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# MODELLING OF THE HEATH STEELE MINES ROD MILL AND EVALUATION OF A COMBINED ROD MILL / GRINDING CIRCUIT SIMULATION

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## SUMMARY

Previous reports have already discussed the simulation of the Heath Steele grinding circuit excluding the rod mill. The present report extends the CIRCUITHS simulator to include rod milling simulation using rod milling data gathered on location. The general rod mill model selected after a literature survey is that proposed by Lynch and Callcott which involves the concepts of breakage function, selection function, classification function and breakage stage. In order to determine the best choice of paramaters to use in the rod mill model, a search algorithm was written to evaluate which of several values of breakage and selection functions could most accurately simulate rod mill product size distributions. In all, 12 different searches were carried out; the best choice of functions determined by optimization involves a breakage function determined experimentally in a small laboratory mill and a discretized selection function. A group of searches involving discretized selection functions with various breakage functions has led to better simulation of experimental size distributions than when a definite shape such as linear or curvilinear on a log/log plot was assigned to S. Following the identification of a best choice of simulation parameters, simulation runs were carried out with two rod mill models, respectively the worst simulator of experimental size distribution among the conditions studied and one of the best set of rod mill simulation parameters. In the two cases, the results are satisfactory and slightly better with the best rod mill model. Thus, the complete simulator, which allows the prediction of size distribution of product going to flotation knowing the rod mill feed characteristics, is a robust tool and will be very useful for applications to Heath Steele grinding circuit optimization, redesign and control.

# A. MODELLING OF THE HEATH STEELE ROD MILL

## 1. Introduction

This study is part of a project sponsored by CANMET, whose objective it is to develop a procedure to simulate industrial comminution circuits. The simulation technique is particularly intended for the study of the grinding behavior of fine grained Pb-Zn-Cu ores of New Brunswick. The Heath Steele Mines grinding circuit has been selected for testing such an approach and developing an expertise in the full scale modelling procedure.

The initial phase of the project has involved a sampling campaign at Heath Steele to acquire the required industrial data (1). This was followed by a complete study of the two stages ball mill grinding and hydrocyclones circuit (2) (see figure 1) which led to the development of a simulator for this part of the Heath Steele grinding circuit (3). The present report deals with the modelling of the rod mill which so far had not been considered. Also, the selected model will be added to the algorithm CIRCUITHS of the above mentioned simulator for overall evaluation of the complete Heath Steele grinding circuit simulation.

## 2. Rod Mill Modelling*

The important physical characteristic of rod mills is that pronounced preferential breakage of the coarser particles occurs and this is responsible for the "screening" effect which has been observed to occur within rod mills. As the ore particles pass through a rod mill, they are subjected to a repetitive series of breakage processes and the "screening" effect operates so that the coarse size ranges are

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* Much of the text and comments given in this section were taken from reference (4).

progressively eliminated. Hydraulic classification also appears to influence the size distribution of particles discharged from a rod mill such that higher specific gravity particles in the mill product are smaller in terms of screen sizes than those of lower specific gravity. Also, in a rod mill, particles are subjected to be broken more severely and/or more rapidly according to their physico-mechanical properties often summarized as their grindability. Aside from the size and the grindabdity of the ore fed to the rod mill, several operating conditions can influence the product particle size distribution obtained, they are to name the most important ones: the feed rate, the mill speed, the rod size and charge as well as the percent solid of the pulp.

To date only the rod mill model proposed by Callcott an Lynch (5) has been accepted as generally adequate for industrial rod mill simulation. They regard the rod mill as containing a series of grinding zones or stages in which both breakage and screening occur. A stage of breakage for a rod mill is defined as the "interval required to eliminate the largest sieve fraction from the feed to the mill in the first instance and there after from the feed to successive stages". The screening or classification which occurs within each stage ensures that no particles in the maximum range of the feed entering a stage are able to leave that stage as particle in the same size range: all must be broken into smaller size ranges. The matrix equation describing this repetitive process can be written as:

$$p = \prod_{j=0}^{j=v} X_j \cdot f$$

where p is the size distribution (fraction retained) vector of the product; f is the size distribution (fraction retained) vector of the feed; $X_j$ is the matrix grinding operator describing the transition from stage j to j + 1 within the mill; v is the number of grinding stages within the mill.

Matrix $X_j$ involves the well known breakage, selection and classification processes, it can be written as:

$$X_j = (I-C)\cdot(B\cdot S + I-S)\cdot\left[I - C\cdot(B\cdot S + I-S)\right]^{-1}$$

Where I is an identity matrix; C is a diagonal classification matrix; B is a lower triangular breakage matrix (fraction retained); S is a diagonal selection matrix.

$X_j$ is maintained constant relative to the largest size fraction of particles entering a stage. For the first stage, element (1,1) in $X_j$ must be zero to ensure that the top element in the product is zero. The size of vectors and matrices must be compatible.

Diagonal Classification Matrix C

Given the definition of a stage of breakage, this requires when $b_{11} \neq 0$ that $C_{1,1}$ should be unity in the first stage, that is, that all particles in this size range should be retained within the breakage zone until they are reduced to less than the lower limiting size. $C_{2,2}$ must be one in stage 2, $C_{3,3}$ in stage 3 and so on. Values equal to zero are usually selected for other elements on the diagonal and it is the case in the present study.

Lower Triangular Breakage Matrix B

Breakage in rod mills is usually considered to be the result of a mixture of shatter and attrition breakage. Different minerals show different breakage behavior in ball milling (5), the same should be expected for rod mills.

The breakage function used to build the rod mill breakage matrix B is often (3,6) taken as the breakage function proposed by Broadbent and Callcott, namely:

$$B\,(x/y) = (1-e^{(-x/y)})\,/(1-e^{-1})$$

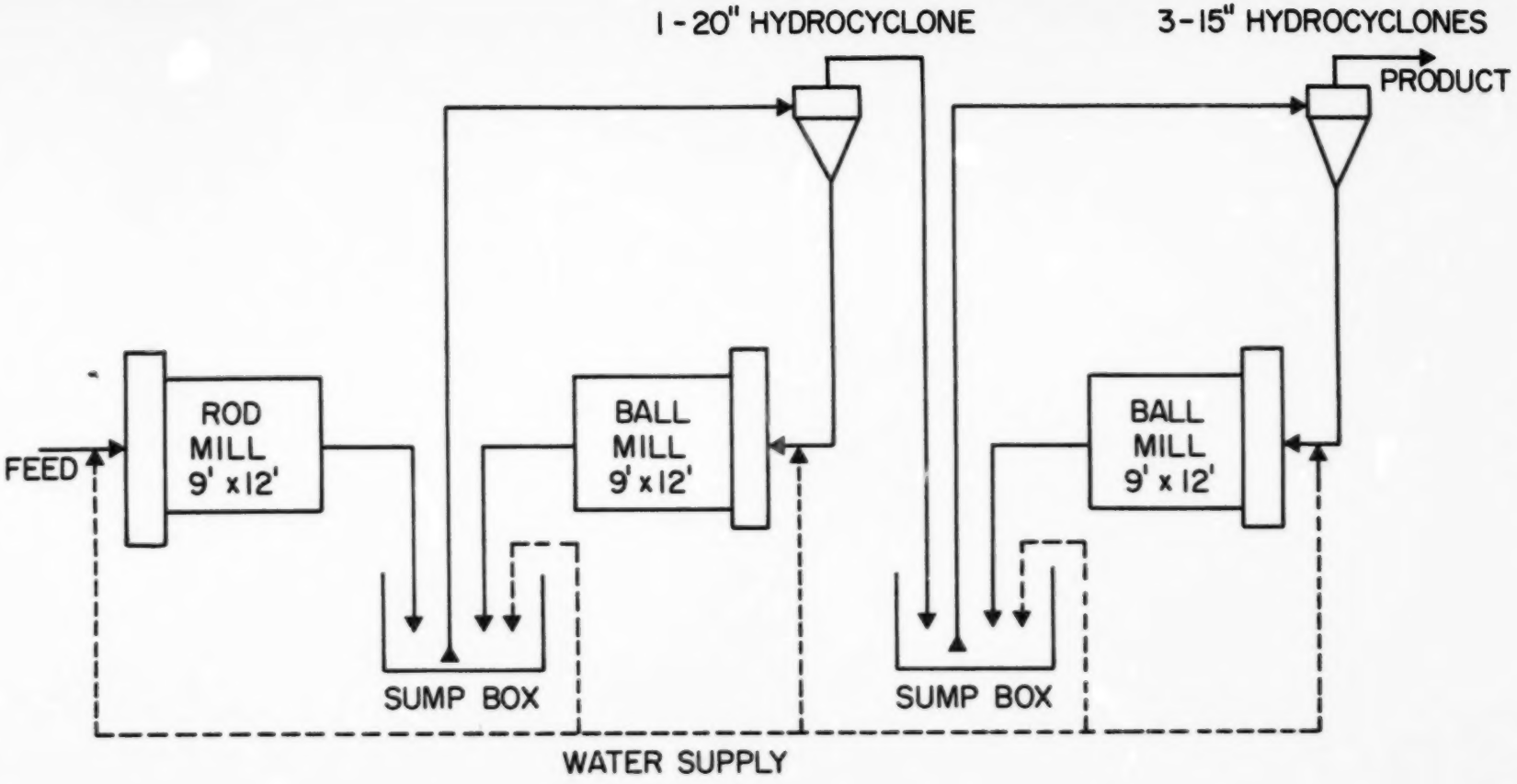



FIG 1. HEATH STEELE GRINDING CIRCUIT FLOW-SHEET

If the fractions x/y are expressed as a geometric progression, then the values in the step matrix B which conform to that geometric progression may be calculated. If the ratio between successive sieves is $2^{-1}$, the numerical elements in the first column of B are: < 0.1980 0.3308 0.2148 0.1225 .0654... > If the ratio is $2^{-0.5}$, the numerical values are: < 0.1004 0.1906 0.1161 0.1361 0.1069... > It should be noted that the first elements are not zero indicating that such functions in Lynch's approach imply that a fraction of the particles maintain their original size following breakage.

Other breakage functions can be used including a more general expression of the one proposed by Broadbent and Callcott, namely:

$$B\ (x/y) = (1-e^{(-x/y)^{\mu}})\ /(1-e^{-1})$$

Where parameter $\mu$ can be adjusted to suit particular industrial results. Also, other forms can be chosen such as those obtained in laboratory and industrial mills through various determinations or optimization schemes.

Diagonal Selection Matrix S

If fixed values are selected for C and B (the original Broadbent Callcott equation), the variations in the ore and machine characteristics are described by the selection matrix. The rod mill diagonal elements in S are generally found to decrease with decrease in particle size as should be expected.

In this case, selection is one of the two variable parameters in the mathematical model of a rod mill process, the other being stages of breakage. The selection matrix then incorporates a description of the ore and mill characteristics, and the number of stages of breakage is related to the feed rate, the mill speed and other process variables.

If only C is fixed, additional variable parameters are required in the mathematical model of the rod mill and the ore characteristics is introduced in both the breakage and selection functions.

The shape of the selection function can take various form to suit the experimental results.

Stage Breakage Matrix X

The stage breakage matrix, $X_j$, includes the individual matrices B, S and C. Change in any of these alters $X_j$ and also alters the product size predicted by the model for a given feed size. The number of stages of breakage v in a grinding process is a measure of the extent to which breakage proceeds and is closely linked to the retention time in the mill. It varies inversely to the feed rate and it has been found that, over the normal range of rod mill operation that the following relationship is approximately correct:

$$(Q: \text{ mill feed rate}) \cdot v^{1.5} = K: \text{constant}$$

The constant K has been termed the mill constant and the mill feed rate Q can be taken in tonnes per hour although the volumetric feed rate could likely be used which would permit comparison of the rod mill behavior of material with different specific gravity. The relationship between feed rate and stage of breakage v was reported to shift slightly when the feed size changes.

## 3. Model Parameters for the Heath Steele Rod Mill

### a) The Rod Mill and Operating Conditions Investigated

The Heath Steele rod mill has a nominal 9-ft diameter and 12-ft length. The mill is of the overflow type and it is fed with 2 15/16-in replacement rods. The ore is a massive sulfide containing chalcopyrite, galena and sphalerite having an overall specific gravity of 4.5. During the sampling campaign, four different operating conditions were investigated; feed rate was varied between 87.1 and 62 metric tons per hour while corresponding pulp percent solid varies between 81.9% and 78.1%. Data for the four test runs are given in Table I, included ore feed and product size distribution associated with feed rate and pulp percent solid. Size distributions are also shown on Figure 2.

### b) Search Algorithm to Determine the Heath Steele Rod Mill Parameters

A search algorithm was programmed in APL to determine the Heath Steele rod mill parameters. The program documentation, flow diagram and program listings are given in Appendix I while the rod mill calculation algorithm and the search algorithm are respectively given in Tables II and III. The procedure consists in a step by step search of parameters for the diagonal of the selection matrix S and, in some cases, for the columns of the breakage matrix B, respectively the selection and breakage functions. The criterium selected is that of the minimum of the sum of the squared deviations between experimental and calculated size product distributions. The search for the minimum is made using the Powell minimization technique programmed in APL. Model parameter determinations were made using a number of breakage functions (experimental and theoretical) and a number of selection function shapes.

TABLE I ROD MILL EXPERIMENTAL DATA

| Screen Size (μm) | SIZE DISTRIBUTION (percent cumulative passing) Run #1 feed | Run #1 product | Run #2 feed | Run #2 product | Run #3 feed | Run #3 product | Run #4 feed | Run #4 product |
|---|---|---|---|---|---|---|---|---|
| 26670 | 97.20 | 100 | 97.70 | 100 | 97.60 | 100 | 97.70 | 100 |
| 18796 | 86.00 | 100 | 81.20 | 100 | 81.30 | 100 | 89.50 | 100 |
| 13208 | 63.80 | 100 | 57.10 | 100 | 58.40 | 100 | 71.80 | 100 |
| 9398 | 52.40 | 100 | 46.60 | 100 | 46.60 | 100 | 60.70 | 100 |
| 6604 | 41.80 | 100 | 37.00 | 100 | 35.40 | 100 | 50.80 | 100 |
| 4699 | 34.00 | 100 | 30.60 | 100 | 28.70 | 100 | 42.90 | 100 |
| 3327 | 29.40 | 99.28 | 26.10 | 100 | 25.10 | 100 | 37.50 | 100 |
| 2362 | 25.20 | 97.74 | 22.90 | 98.27 | 22.20 | 99.33 | 32.60 | 99.88 |
| 1651 | 21.30 | 92.78 | 19.60 | 94.35 | 19.30 | 97.13 | 27.70 | 99.34 |
| 1168 | 18.40 | 84.05 | 17.10 | 87.47 | 17.00 | 90.90 | 23.90 | 97.20 |
| 833 | 16.10 | 72.96 | 14.90 | 77.42 | 15.00 | 81.09 | 20.80 | 92.08 |
| 589 | 14.40 | 63.67 | 13.40 | 67.69 | 13.50 | 71.29 | 18.60 | 84.55 |
| 417 | 13.10 | 55.19 | 12.10 | 58.21 | 12.30 | 63.59 | 16.90 | 75.23 |
| 295 | 11.90 | 48.28 | 11.10 | 50.32 | 11.30 | 53.92 | 15.60 | 66.10 |
| 210 | 10.90 | 42.81 | 10.20 | 43.96 | 10.40 | 47.63 | 14.40 | 58.08 |
| 147 | 9.80 | 37.59 | 9.30 | 37.75 | 9.50 | 41.65 | 13.20 | 50.19 |
| 105 | 8.90 | 33.46 | 8.50 | 33.20 | 8.70 | 37.16 | 12.10 | 44.29 |
| 74 | 8.10 | 29.79 | 7.70 | 28.89 | 8.00 | 32.99 | 11.00 | 38.62 |
| 53 | 6.90 | 25.69 | 6.90 | 24.39 | 7.00 | 28.48 | 9.80 | 32.93 |
| 37 | 4.80 | 19.55 | 5.10 | 17.21 | 5.00 | 21.37 | 7.00 | 24.01 |
| 26 | 4.50 | 16.35 | 4.60 | 14.48 | 4.60 | 18.57 | 6.20 | 20.15 |
| feed rate (m.t./h) | 87.1 | | 79.4 | | 69.9 | | 62 | |
| Pulp%solid | 81.9 | | 80.7 | | 80 | | 78.1 | |

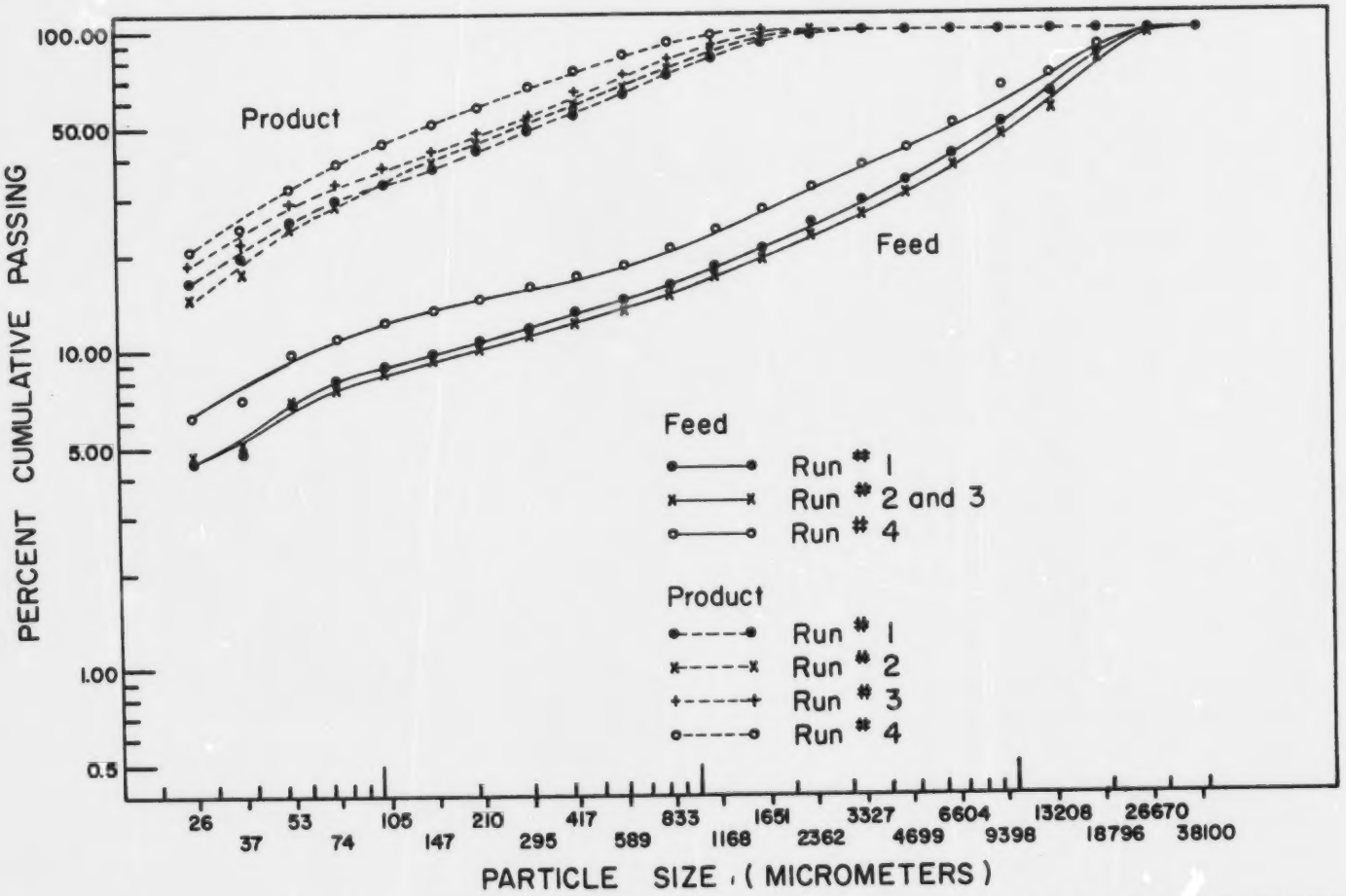



FIG 2. ROD MILL FEED AND PRODUCT EXPERIMENTAL SIZE DISTRIBUTIONS

TABLE II

Algorithm for Rod Mill Calculations

1) INPUT DATA OF PROGRAMS AND SUBPROGRAMS

2) CALCULATION OF THE CUMULATIVE BREAKAGE FUNCTION B

CALCULATION OF THE MATRIX OF NON-CUMULATIVE ELEMENTS OF B: $b_{ij}$

CALCULATION OF THE SELECTION FUNCTION

3) CALCULATION OF THE NUMBER OF BREAKAGE STAGES

$v = (K/Q)^{1/1.5}$ (v: real positive number)

4) CALCULATION OF THE INITIAL BREAKAGE MATRIX

$X_1 = (I-C) \cdot (B \cdot S + I - S) \cdot \left[ I - C \cdot (B \cdot S + I - S) \right]^{-1}$

5) CALCULATION OF THE ROD MILL PRODUCT FOR BREAKING STAGE i: $P_i = X_i P_{i-1}$

$i = 1,2,3 \ldots n \quad . \quad n \leq v$

$p_o = f$ = feed

6) ADJUSTMENT OF MATRIX $X_i$ FOR THE $(i+1)$ BREAKING STAGE

7) TEST: HAS THE MINIMUM NUMBER OF INTEGER BREAKING STAGE BEEN CALCULATED ?

NO: RETURN TO 5)

YES: GO TO 8)

8) CALCULATION OF THE FINAL PRODUCT OF THE v STAGES, FOR THE FRACTIONAL PART OF v

9) COMPARISON OF EXPERIMENTAL AND CALCULATED ROD MILL PRODUCTS

CALCULATION OF DEVIATIONS AND OF THE SUM OF SQUARED DEVIATIONS

TABLE III

Search Algorithm for the Minimum of Squared Deviations

1) DATA INPUT

vector "x" for screen sizes in microns
vector of feed size distributions
vector of product size distributions
vector of the feed rates corresponding to the observed feed and product size distributions
vector B of an experimental breakage function when used to initiate calculations.

2) CHOICE OF INITIAL VALUES OF OPTIMIZATION VARIABLES

Coefficients $\mu, a_1$ and/or $a_2$ and/or $a_3$, and of constant K fixing the parameters

$$B = \left[1 - e^{-(x/y)^{\mu}}\right] / (1 - e^{-1})$$

$$S = e\left[a_0 + a_1 (\ln x) + a_2 (\ln x)^2 + a_3 (\ln x)^3\right]$$

$$v = (K + Q)^{1/1.5}$$

or choice of initial values for $\mu$, K and S when S is evaluated point by point.

3) APPLICATION OF THE POWELL MULTI-DIMENSIONAL SEARCH

with participation of the algorithm for rod mill calculations upon to the final solution.

4) END OF SEARCH AND PRINT-OUT OF OPTIMUM SOLUTION

Aside from providing the parameters for the selection function and the breakage function as the case may be, the search algorithm also provides calculated breakage stages for each run, a value for the mill constant, calculated size distributions for the rod mill product as well as an evaluation of minimum squared deviations F. This last value gives an indication of the quality of the fit.

c) Results of Determinations

Several different searches were made using various shapes for B and S; search conditions and results are presented and discussed briefly below:

Searches with shape assignation for S

- Search # 1

Breakage function: (see figure 3).

a) as determined from industrial ball mill studies at Heath Steele (primary circuit) (2)
b) assumed normalisable
c) no product of initial size upon breakage ($b_{jj} = 0$)
d) B : < 1.0, 0.807, 0.647, 0.519, 0.416, 0.333, 0.267, 0.214, 0.172, 0.138, 0.106, 0.082, 0.064, 0.050, 0.039, 0.030, 0.024, 0.018, 0.014, 0.011, 0.0083 >

Selection function: $S = a \times^{\alpha}$

-------- R e s u l t s --------

Selection function: $\alpha = 0.78$ (see figure 4).
Mill constant: $K = 1329.8 \quad Qv^{1.5} = K$
Breakage stages: $v_1$ to $v_4$ : 6.15, 6.55, 7.13 and 7.72
Value of the sum of squared deviations: $F = 10.019 \times 10^{-3}$

- Search # 2

Breakage function: (see figure 3).

a) as determined from industrial ball mill studies at Heath Steele (secondary circuit)

b) assumed normalisable

c) no product of initial size upon breakage

d) B : <1.0, 0.557, 0.427, 0.327, 0.2506, 0.1921, 0.1472, 0.1128, 0.0799, 0.0566, 0.0401, 0.0284, 0.0201, 0.0143, 0.0101, 0.0071, 0.0051, 0.0036, 0.0026, 0.0018, 0.0012, 0.0>

Selection function: $S = a\ x^{\alpha}$

-------- R e s u l t s --------

Selection function: $\alpha = 0.4507$ (see figure 4).

Mill constant: $K = 1280.1\ \ Qv^{1.5} = K$

Breakage stages: $v_1$ to $v_4$ : 6, 6.382, 6.948 and 7.526

Value of the sum of squared deviations: $F = 13.221 \times 10^{-3}$

- Search # 3

Breakage function:

a) $B\ (x/y) = \left[1 - e^{-(x/y)^{\mu}}\right] / \ (1 - e^{-1})$

($\mu$ : variable to be optimized)

b) assumed normalisable

c) no product of initial size upon breakage

Selection function: $S = a\ x^{\alpha}$

-------- R e s u l t s --------

Breakage function: $\mu = 0.5607$ (see figure 3)

Selection function: $\alpha = 1.814$ (see figure 4)

Mill constant: $K = 1765.7\ \ Qv^{1.5} = K$

Breakage stages: $v_1$ to $v_4$ : 7.435, 7.908, 8.609 and 9.326

Value of the sum of squared deviations: $F = 6.0087 \times 10^{-3}$

Size distributions: (see figures 5 to 8)

- Search # 4

Breakage function: as for search # 3

Selection function:

$$\ln S = 1 + b(\ln x) + c(\ln x)^2$$

-------- R e s u l t s --------

Breakage function: $\mu = 0.5607$ (see figure 3)

Selection function: $b = 1.814$

$c = -4.66 \times 10^{-18}$

(see figure 4)

Mill constant: $K = 1765.7$

Breakage stages: $v_1$ to $v_4$ : 7.43, 7.91, 8.61 and 9.33

Value of the sum of squared deviations: $F = 6.0087 \times 10^{-3}$

- Search # 5

Breakage function: as for searches # 3 and # 4

Selection function:

$$\ln S = 1 + b \ln x + c(\ln x)^2 + d(\ln x)^3$$

-------- R e s u l t s --------

Breakage function: $\mu = 0.5607$ (see figure 3)

Selection function: (see figure 4)

$b = 1.814$ $c = 5.31 \times 10^{-18}$ $d = 2.93 \times 10^{-18}$

Mill constant: $K = 1765.7$

Breakage stages: $v_1$ to $v_4$ : 7.43, 7.91, 8.61 and 9.33

Value of the sum of squared deviations: $F = 6.008 \times 10^{-3}$

No significant curvature is accepted by S .

- Search # 6

Breakage function:

a) $B(x/y) = (1 - e^{-(x/y)^{\mu}}) / (1 - e^{-1})$
   ($\mu$: variable to be optimized)

b) assumed normalisable

c) product of initial size permitted ($b_{11} \neq 0$)

Selection function:

$$\ln S = a + b (\ln x) + c (\ln x)^2 + d (\ln x)^3$$

-------- R e s u l t s --------

Breakage function: $\mu = 0.5607$ (see figure 3)

Selection function:

$b = 1.778$ $c = -2.66 \times 10^{-18}$ $d = 8.239 \times 10^{-18}$

Mill constant: $K = 1846.5$ $Qv^{1.5} = K$

Breakage stages: $v_1$ to $v_4$ : 7.65, 8.15, 8.87 and 9.61

Value of the sum of squared deviations: $F = 6.248 \times 10^{-3}$

Note: F is higher, thus a B with product of the initial size permitted leads to a poorer fit of the model.

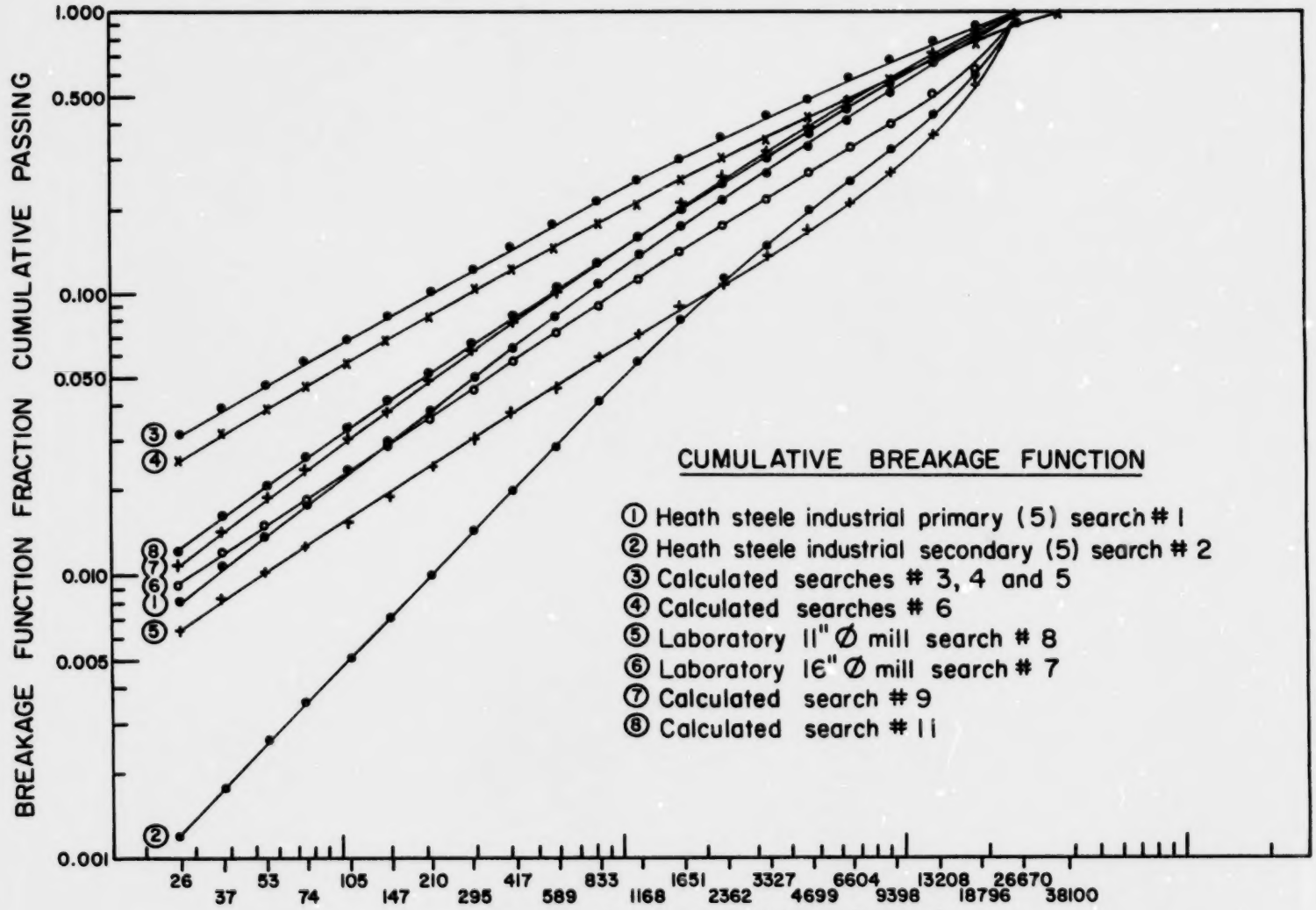



FIG . 3 BREAKAGE FUNCTIONS

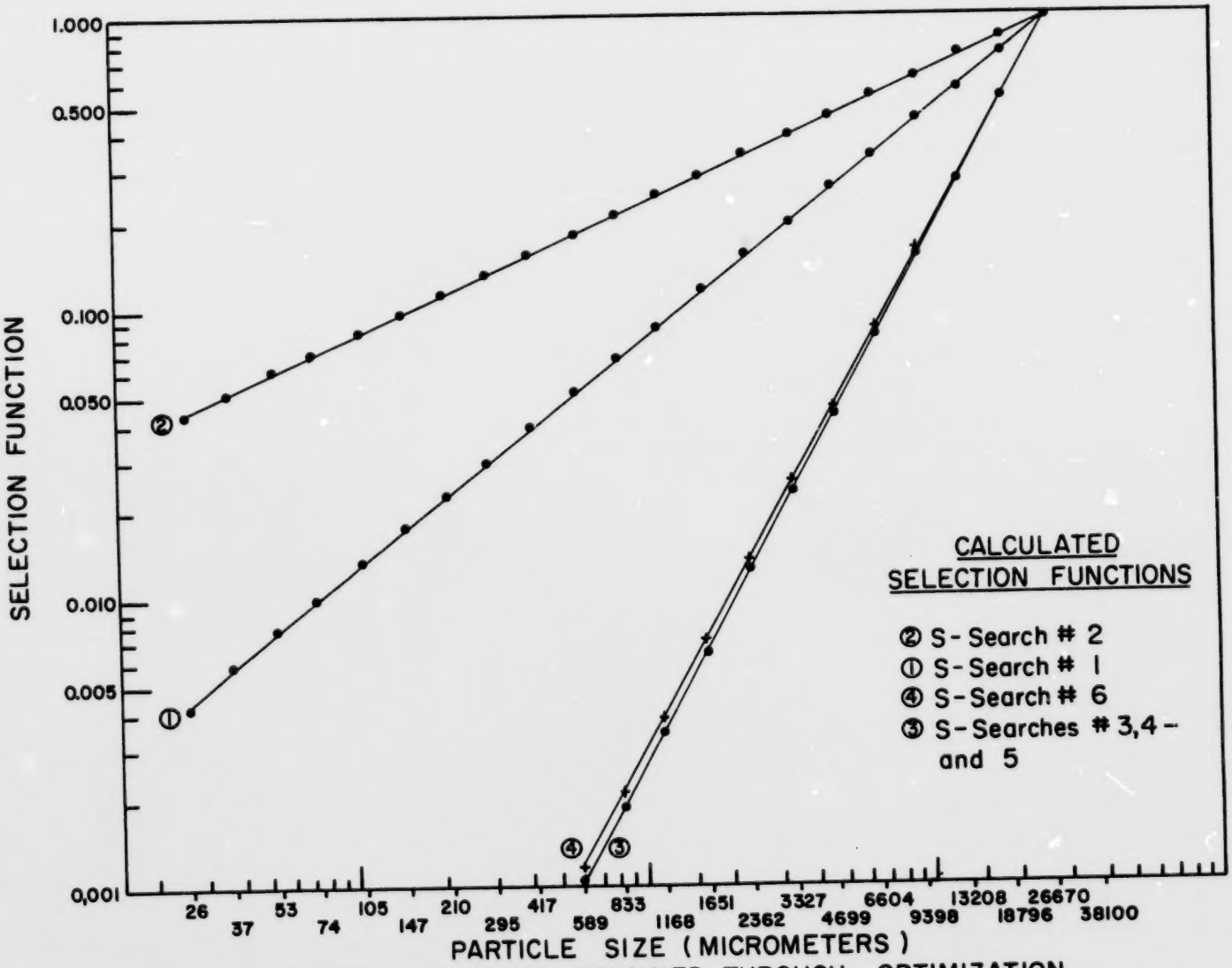



FIG 4. SELECTION FUNCTIONS OBTAINED THROUGH OPTIMIZATION

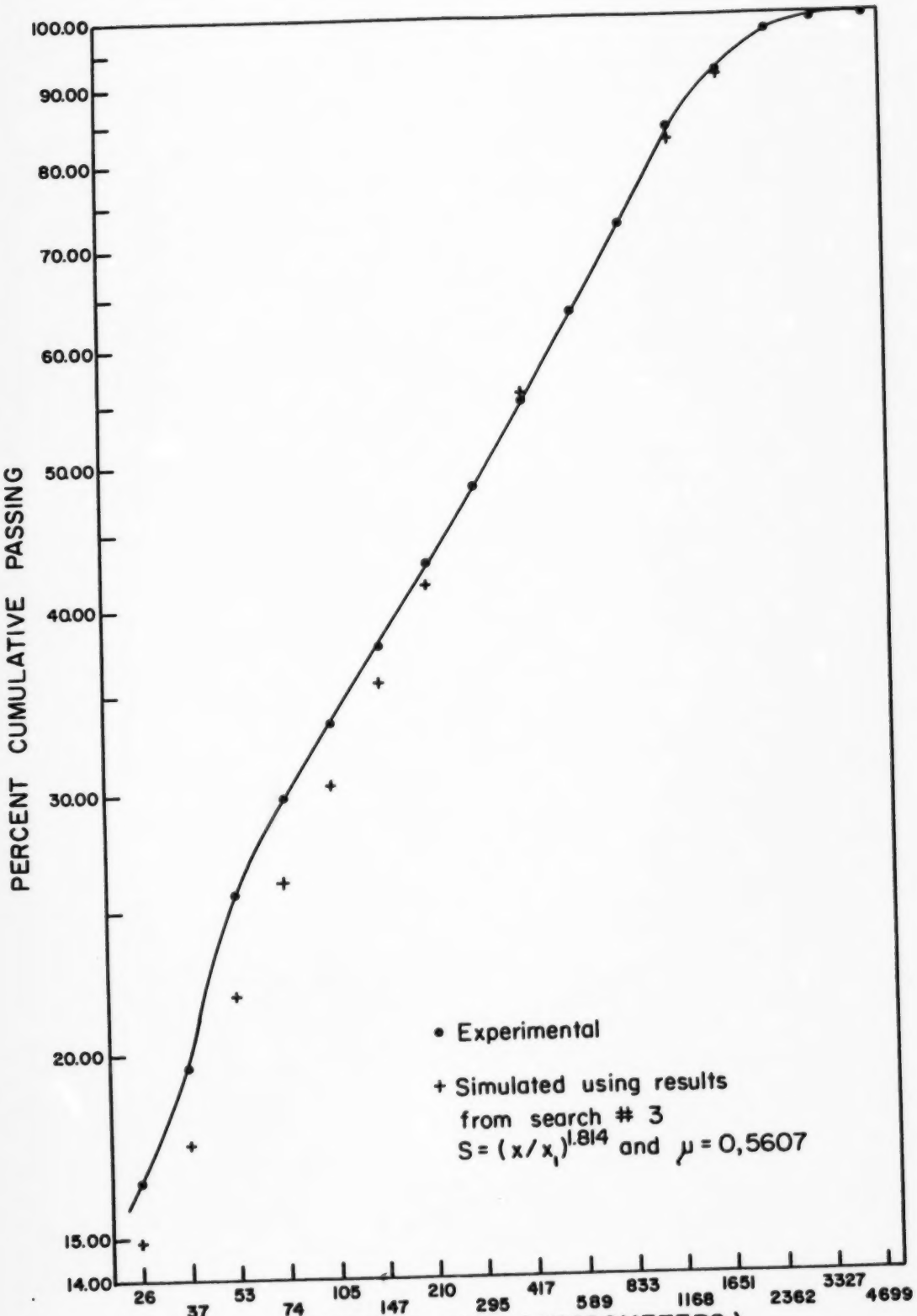



FIG. 5 EXPERIMENTAL AND SIMULATED GRINDING PRODUCTS, RUN # 1. FEED RATE 87,1 t/h

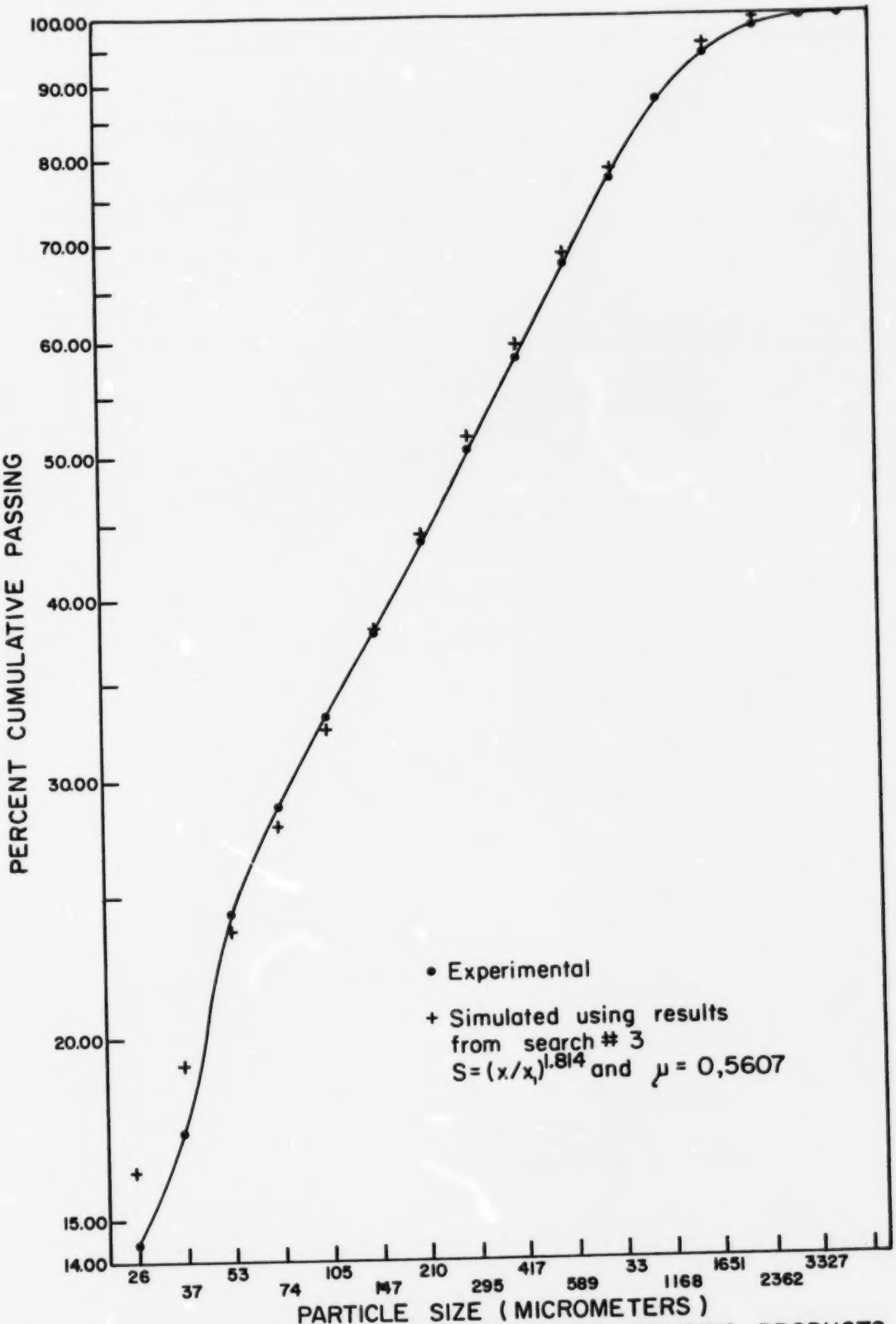



FIG. 6 EXPERIMENTAL AND SIMULATED GRINDING PRODUCTS, RUN#2, FEED RATE 79.4 t/h

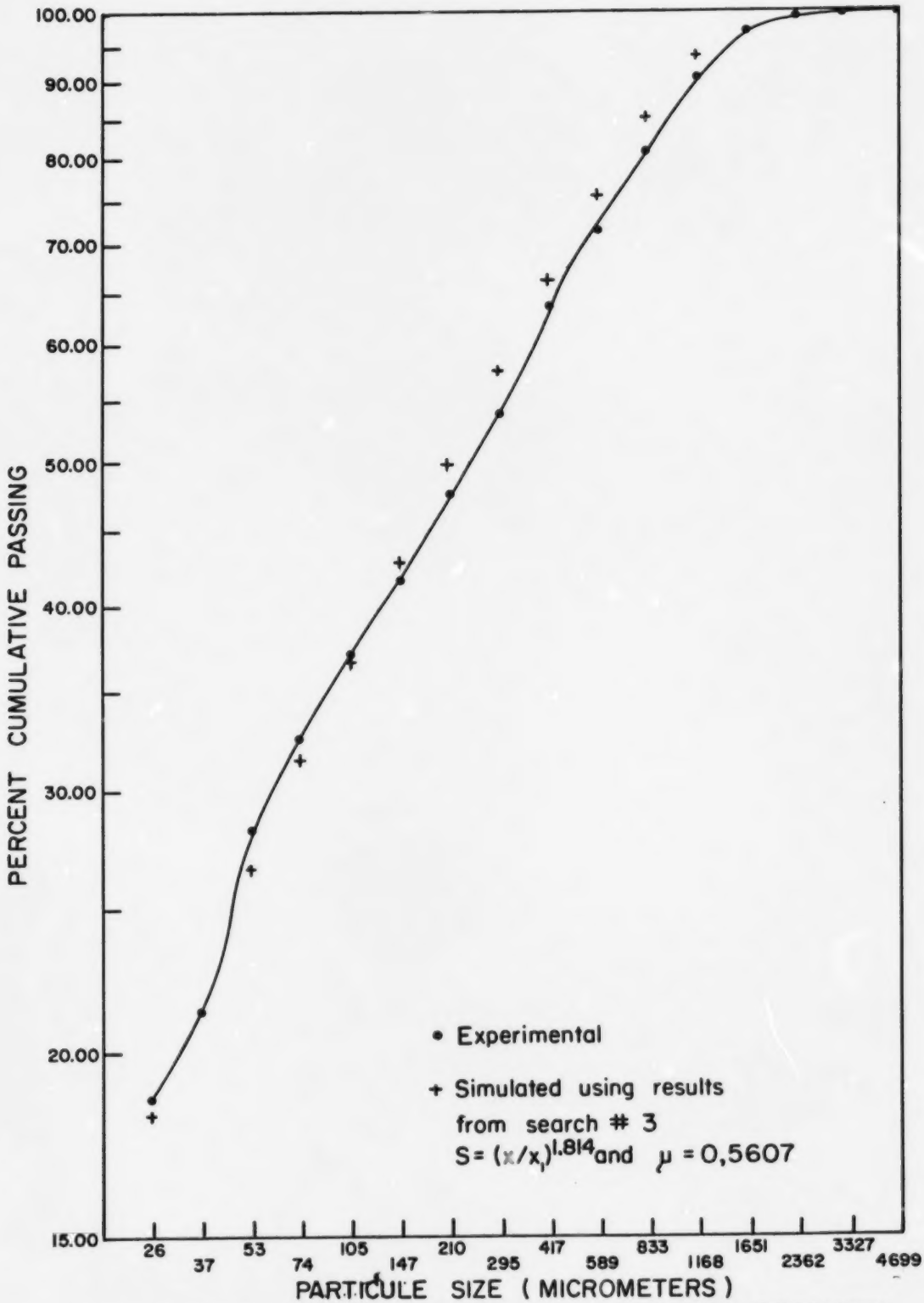



FIG. 7 EXPERIMENTAL AND SIMULATED GRINDING PRODUCTS, RUN # 3 FEED RATE 69.9 t/h

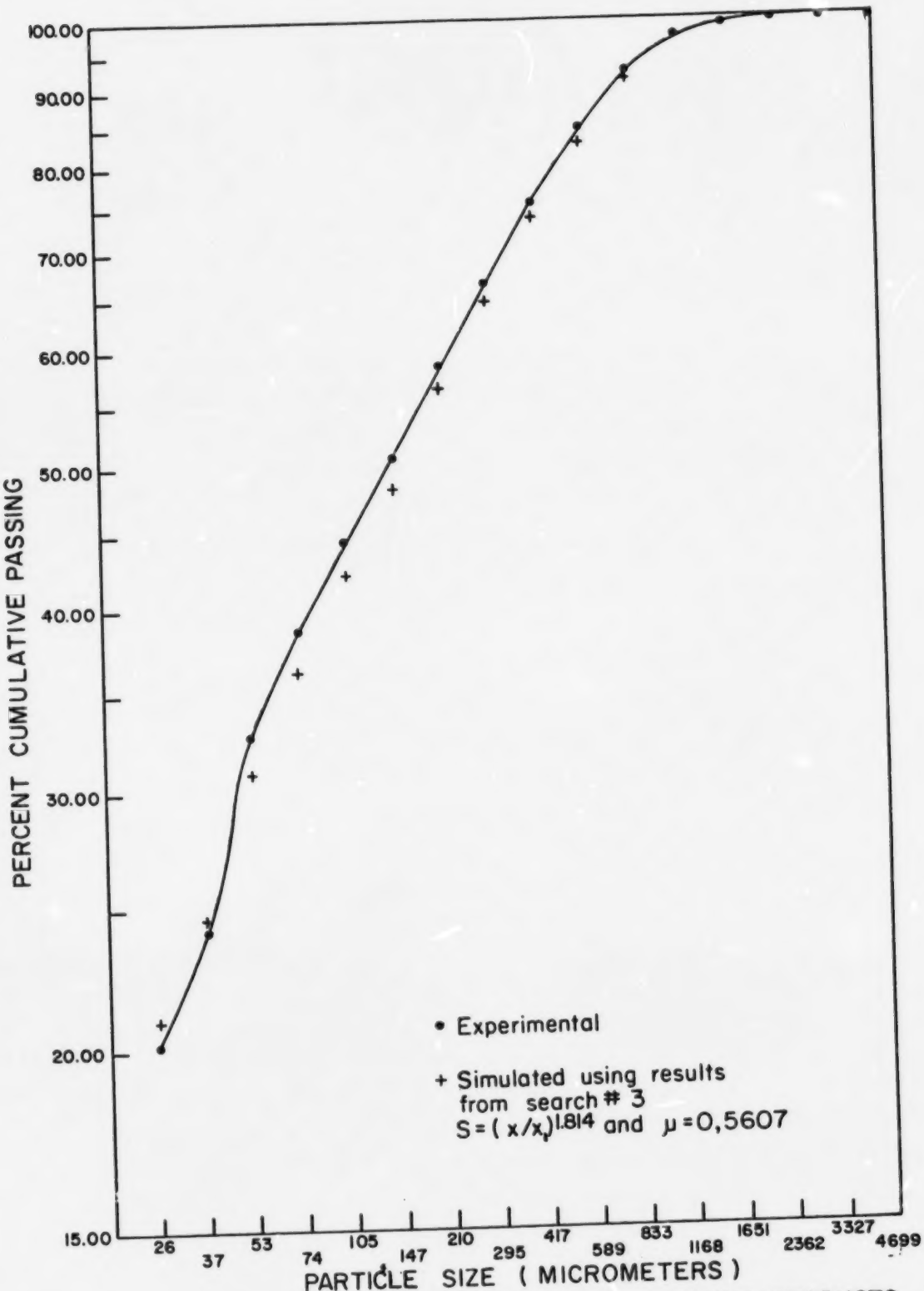



FIG. 8 EXPERIMENTAL AND SIMULATED GRINDING PRODUCTS, RUN # 4 FEED RATE 62 t/h

Searches with point by point evaluation of S with no shape restriction

- Search # 7

Breakage function:

a) as determined from laboratory continuous grinding in a 16" Ø mill (6)

b) assumed normalisable

c) no product of initial size upon breakage

d) B : <1.0, 0.634, 0.509, 0.409, 0.328, 0.264, 0.212, 0.170, 0.137, 0.110, 0.089, 0.071, 0.0568, 0.0456, 0.0366, 0.0291, 0.0235, 0.0187, 0.0152, 010121, 0.0094 >

Selection function: no shape restriction ($S \leq 1$)

-------- R e s u l t s --------

Selection function: very variable (figure 9 and table IV)

Mill constant: K = 1448 $Qv^{1.5} = K$

Breakage stages: $v_1$ to $v_4$ : 6.51, 6.93, 7.54 and 8.17

Value of the sum of squared deviations: $F = 3.93 \times 10^{-3}$

Size distributions: figures 10 to 13

- Search # 8

Breakage function:

a) as determined from laboratory batch grinding in a 11-inch diameter mill (6)

b) assumed normalisable

c) no product of initial size upon breakage

d) B : <1.0, 0.563, 0.357, 0.268, 0.209, 0.167, 0.134, 0.107, 0.088, 0.071, 0.058, 0.045, 0.0371, 0.0299, 0.0242, 0.0194, 0.0158, 0.0127, 0.0103, 0.0083, 0.0065, 0.0 >

Selection function: no shape restriction ($S \leq 1$)

-------- R e s u l t s --------

Selection function: very variable (figure 9 and table IV)
Mill constant: $K = 1530 \quad Qv^{1.5} = K$
Breakage stages: $v_1$ to $v_4$ : 6.76, 7.19, 7.83 and 8.48
Value of the sum of squared deviations: $F = 3.89 \times 10^{-3}$
Size distributions: figures 10 to 13

- Search # 9

Breakage function:
a) $B(x/y) = \left(1 - e^{-(x/y)^{\mu}}\right) / (1 - e^{-1})$
($\mu$ : variable to be optimized)
b) assumed normalisable
c) no product of initial size upon breakage
Selection function: no shape restriction ($S \leq 1$)

-------- R e s u l t s --------

Breakage function: $\mu = 0.714$
B : < 1.0, 0.856, 0.718, 0.598, 0.488, 0.398, 0.320, 0.257, 0.203, 0.161, 0.128, 0.101, 0.0792, 0.0622, 0.0490, 0.0381, 0.0301, 0.0235, 0.0185, 0.0143, 0.0108, 0.0 >
Selection function: very variable (figure 9 and table IV)
Mill constant: $K = 1567 \quad Qv^{1.5} = K$
Breakage stages: $v_1$ to $v_4$ : 6.86, 7.30, 7.95 and 8.61
Value of the sum of squared deviations: $F = 3.98 \times 10^{-3}$

- Search # 10

Breakage function:

a) $B(x/y) = (1 - e^{-x/y}) \;/\; (1 - e^{-1})$

b) assumed normalisable

c) product of initial size permitted upon breakage (y is taken as the geometric average of the initial particle size)

d) B : <1.00, 0.897, 0.705, 0.537, 0.404, 0.296, 0.217, 0.157, 0.113, 0.0798, 0.0569, 0.0408, 0.0289, 0.0205, 0.0146, 0.0104, 0.00728, 0.00520, 0.00367, 0.00263, 0.00184, 0.00124 >

Selection function: no shape restriction ($S \leq 1$)

-------- R e s u l t s --------

Selection function: very variable (table IV)

Mill constant: $K = 1375 \quad Qv^{1.5} = K$

Breakage stages: $v_1$ to $v_4$ : 6.29, 6.69, 7.29 and 7.89

Value of the sum of squared deviations: $F = 4.71 \times 10^{-3}$

- Search # 11

Breakage function:

a) $B(x/y) = \left[1 - e^{-(x/y)^{\mu}}\right] \;/\; (1 - e^{-1})$

($\mu$ : variable to be optimized)

b) normalisable

c) product of initial size permitted upon breakage (y is taken as the geometric average of the initial particle size)

Selection function: no shape restriction ($S \leq 1$)

-------- R e s u l t s --------

Breakage function: $\mu = 0.676$

B : <1.00, 0.930, 0.7960, 0.6702, 0.5608, 0.4613, 0.3790, 0.3084, 0.2500, 0.1998, 0.1603, 0.1289, 0.1028, 0.0820, 0.0652, 0.0521, 0.0410, 0.0328, 0.0259, 0.0207, 0.0163, 0.0125 >

Selection function: very variable (table IV)

Mill constant: $K = 1714 \quad Qv^{1.5} = K$

Breakage stages: $v_1$ to $v_4$ : 7.29, 7.75, 8.44 and 9.14

Value of the sum of squared deviations: $F = 4.45 \times 10^{-3}$

- Search # 12

Breakage function:

a) as determined from industrial ball mill studies at Heath Steele primary circuit (5)

b) assumed normalisable

c) no product of initial size upon breakage

d) B <1.0, 0.807, 0.647, 0.519, 0.416, 0.333, 0.267, 0.214, 0.172, 0.138, 0.106, 0.082, 0.064, 0.050, 0.039, 0.030, 0.024, 0.018, 0.014, 0.011, 0.033 >

Selection function: no shape restriction ($S < 1$)

-------- R e s u l t s --------

Selection function: very variable (table IV)

Mill constant: $K = 1339 \quad Qv^{1.5} = K$

Breakage stages: $v_1$ to $v_4$ : 6.183, 6.577, 7.16 and 7.756

Value of the sum of squared deviations: $F = 3.9058 \times 10^{-3}$

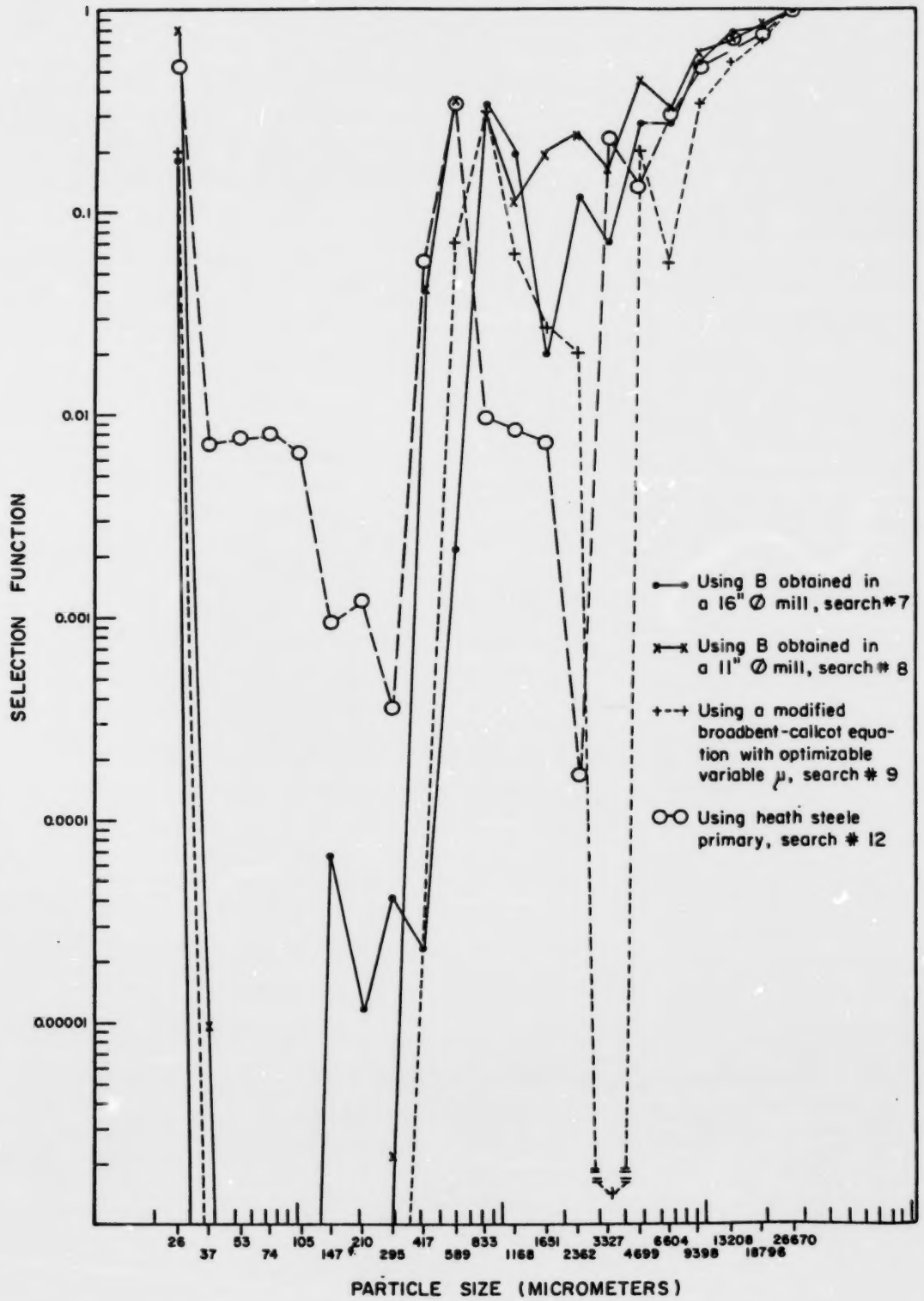



FIG. 9 DISCRETIZED SELECTION FUNCTIONS EVALUATED THROUGH OPTIMIZATION

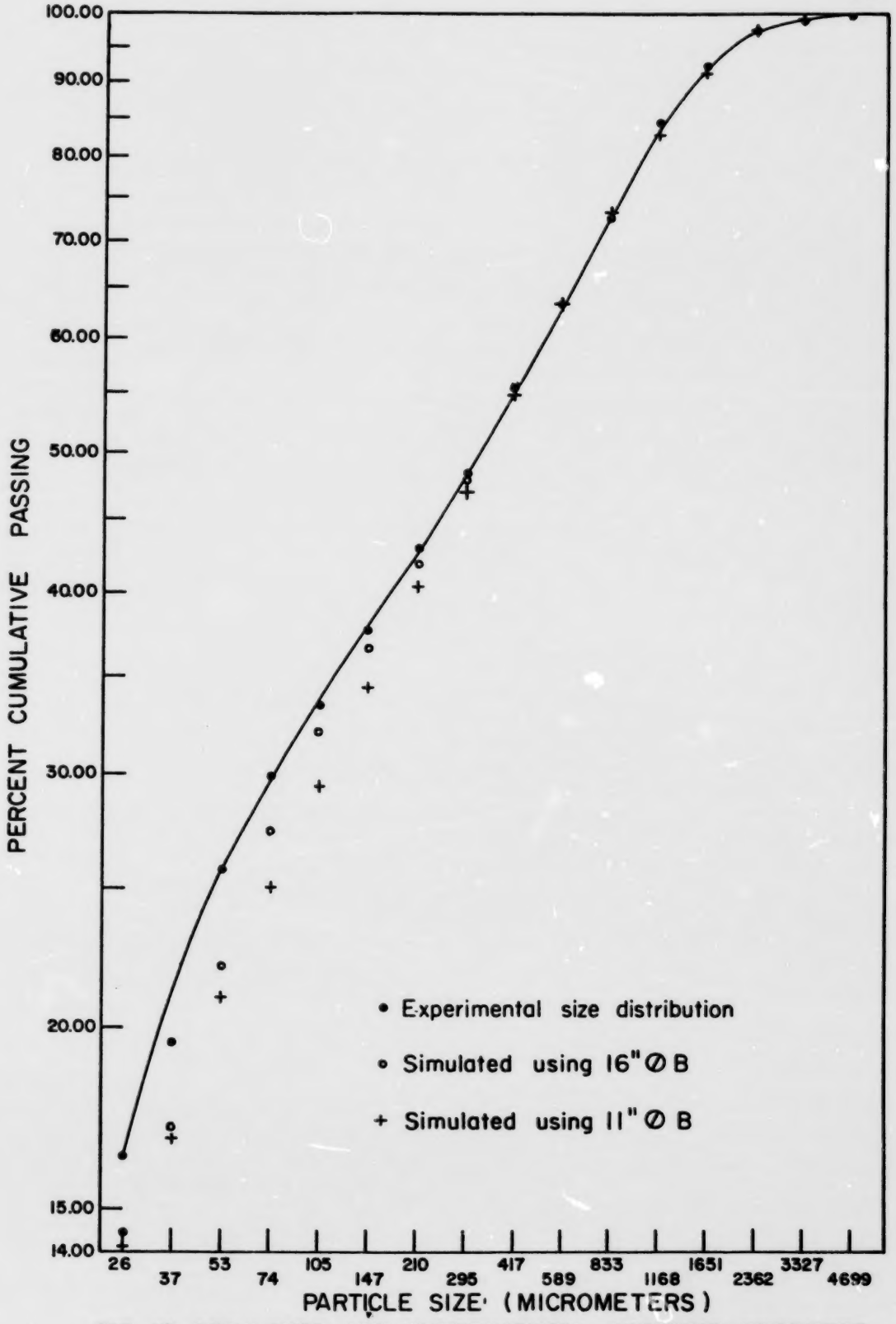



FIG. 10 SIMULATED AND EXPERIMENTAL GRINDING PRODUCTS, RUN # 1, FEED RATE 87.1 t/h. (Discretized selection function)

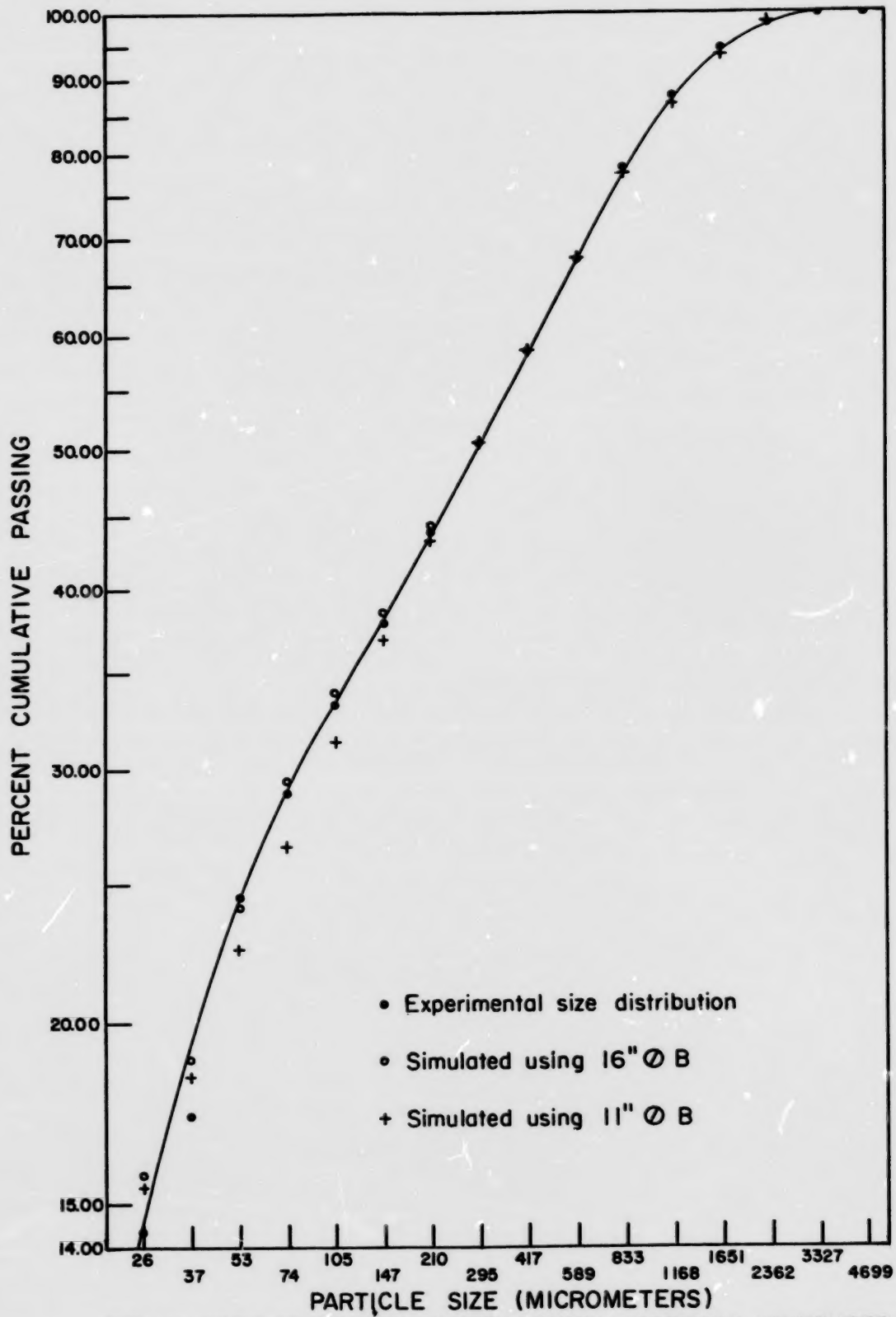



FIG. 11 SIMULATED AND EXPERIMENTAL GRINDING PRODUCTS, RUN # 2, FEED RATE 79.4 t/h. (Discretized selection function)

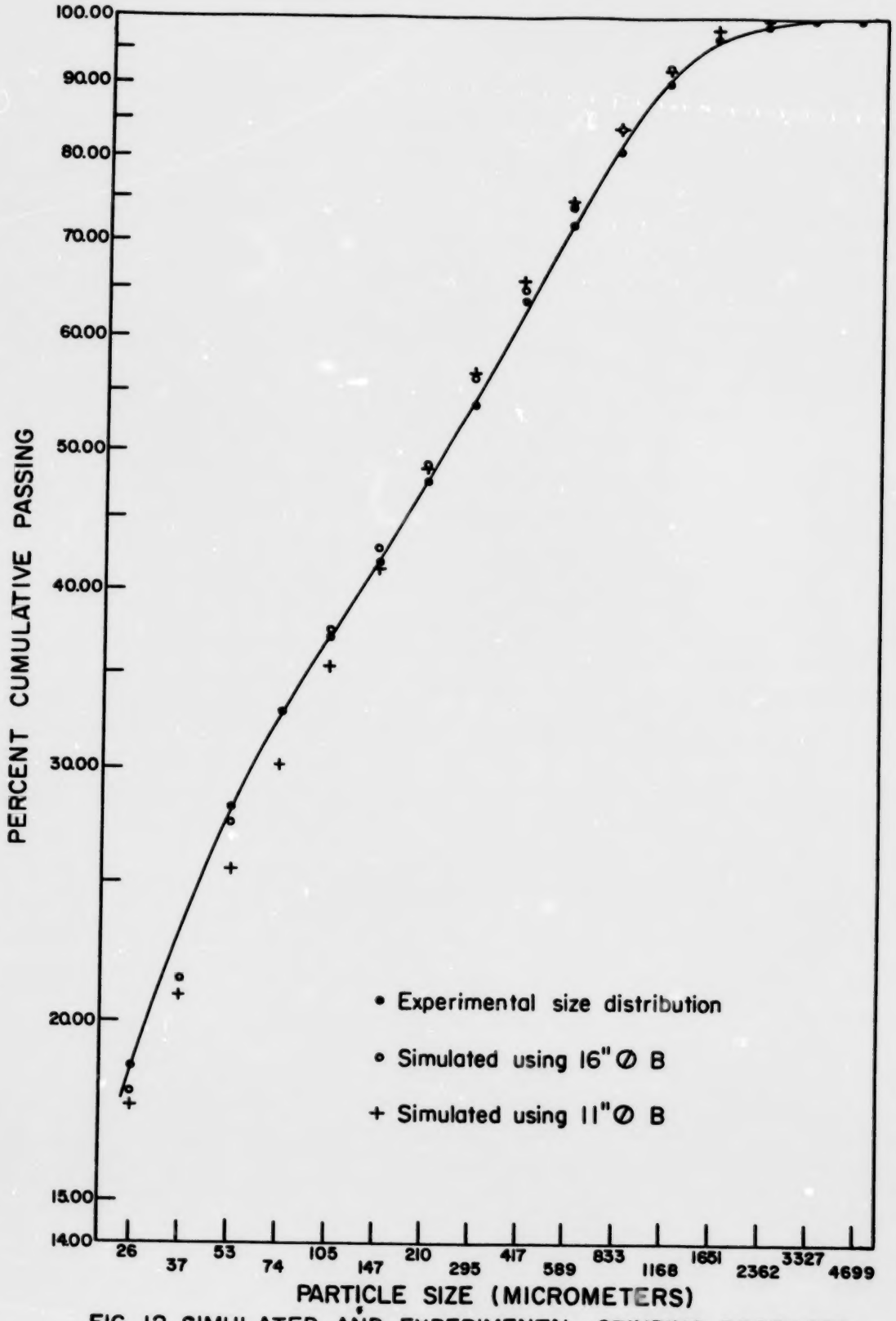



FIG. 12 SIMULATED AND EXPERIMENTAL GRINDING PRODUCTS, RUN # 3, FEED RATE 69.9 t/h. (Discretized selection function)

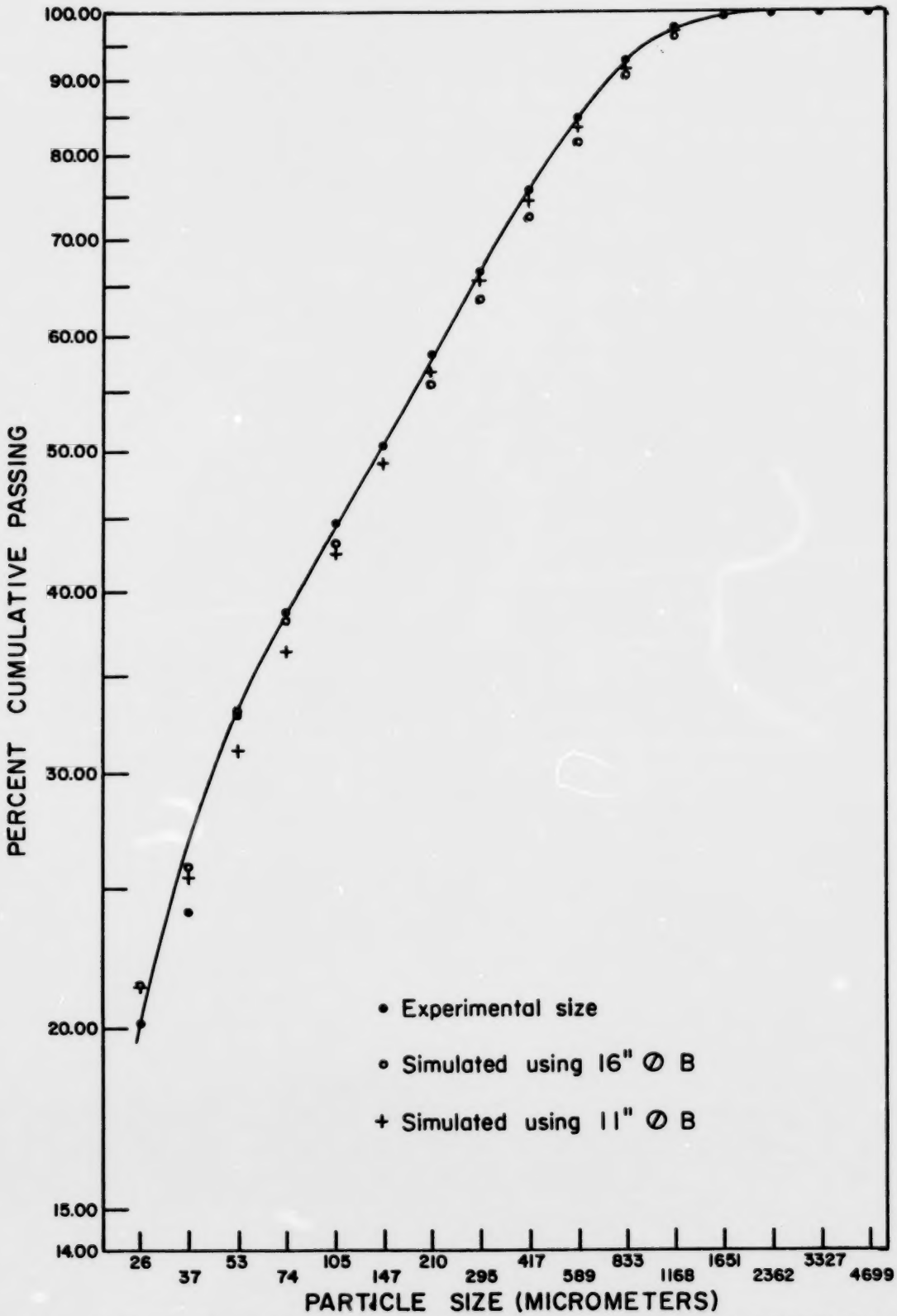



FIG. 13 SIMULATED AND EXPERIMENTAL GRINDING PRODUCTS, RUN # 4, FEED RATE 62 t/h. (Discretized selection function)

TABLE IV - CALCULATED SELECTION FUNCTIONS FROM VARIOUS SEARCHES

| Search # 7 | Search # 8 | Search # 9 | Search # 10 | Search # 11 | Search # 12 |
|---|---|---|---|---|---|
| 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| .817 | .839 | .703 | .853 | .633 | .743 |
| .707 | .730 | .532 | .799 | .513 | .725 |
| .509 | .602 | .339 | .597 | .159 | .531 |
| .273 | .321 | .0574 | .351 | .171 | .304 |
| .277 | .457 | .205 | .222 | .0628 | .131 |
| .138 | .167 | 0 | .312 | $.332 \times 10^{-5}$ | .230 |
| .0669 | .242 | .0205 | .0972 | .0237 | $.164 \times 10^{-3}$ |
| .118 | .198 | .0269 | .254 | $.222 \times 10^{-4}$ | .0730 |
| .0196 | .110 | .0623 | .186 | .225 | .0844 |
| .197 | .305 | .319 | .227 | .204 | .0947 |
| .341 | .357 | .0714 | .526 | $.396 \times 10^{-3}$ | .343 |
| .00219 | .0419 | $.520 \times 10^{-5}$ | .102 | $.529 \times 10^{-3}$ | .0568 |
| $.235 \times 10^{-3}$ | $.223 \times 10^{-4}$ | $.226 \times 10^{-5}$ | .00271 | $.283 \times 10^{-3}$ | $.350 \times 10^{-3}$ |
| $.418 \times 10^{-3}$ | 0 | 0 | .161 | $.153 \times 10^{-3}$ | $.122 \times 10^{-2}$ |
| $.119 \times 10^{-3}$ | 0 | 0 | .142 | $.799 \times 10^{-4}$ | $.948 \times 10^{-3}$ |
| $.671 \times 10^{-3}$ | 0 | 0 | 0 | $.434 \times 10^{-4}$ | $.644 \times 10^{-2}$ |
| 0 | 0 | 0 | 0 | $.230 \times 10^{-4}$ | $.800 \times 10^{-2}$ |
| 0 | 0 | 0 | $2.41 \times 10^{-5}$ | $.126 \times 10^{-4}$ | $.760 \times 10^{-2}$ |
| 0 | $.999 \times 10^{-4}$ | 0 | $1.99 \times 10^{-5}$ | $.655 \times 10^{-5}$ | $.745 \times 10^{-2}$ |
| .205 | .815 | .202 | .999 | $.321 \times 10^{-5}$ | .530 |
| 0 | 0 | 0 | 0 | 0 | 0 |

## 4. Discussion of the results

The quality of the fit between experimental and simulated rod mill product size distributions, as expressed by the value of functional F (sum of squared deviations), is controlled by several factors which can be summarized as follows:

a) Restrictions on the breakage function; it can be chosen as:
   i) the Broadbent-Callcott original equation;
   ii) a modified Broadbent-Callcott equation containing an adjustable variable, $\mu$;
   iii) an experimental breakage function or an estimated breakage function obtained from industrial or laboratory ball mill results;
   and iv) normalisable or not (not tested);
   v) particles of original size permitted or not in the breakage product.

b) Restrictions on the Selection function, it can be described by:
   i) a discretized function evaluated point by point;
   ii) a linear equation on a log-log plot:

$$S = (x/x_1)^{\chi}$$

   iii) a curvilinear equation on a log-log plot of the type:

$$S = e^{(ao + \sum_{i=1}^{n} a_i (\ln X)^i)}$$

c) Restriction on the $Q.v^{\gamma} = \kappa$ relationship.
   Even though $\gamma$ is usually selected as 1.5, other values can be assigned to $\gamma$. (8)

Function B and S can be adjusted simultaneously. When the slope of B on the usual log-log plot increases, that of S decreases and

inversely for the same feed and product. This follows from the search method and is related to the mathematical form of the model. The criteria being that of the least square, the choice of one or two parameters, for example the number of stages v or the B function, leads to a compensation effect, an adjustment of the other slopes obtained for B are always smaller than those for S.

## Optimum choice of parameters for the Heath Steele Rod Mill Simulation

Table V provides a summary of the various search conditions tested and of the calculated deviations between observed and simulated mill product size distributions using relevent estimated rod mill parameters. The worst agreement between observed and simulated distributions was obtained with search # 2 where the breakage function was taken as a calculated industrial function determined from the Heath Steele secondary ball mill whereas the selection was selected as linear on a log/log plot. The best agreement between observed and simulated distributions was obtained for search # 8 where the breakage function was taken as an experimental function determined in an 11"Ø laboratory ball mill whereas the selection was taken as evaluated in a discrete manner. However, searches # 7 and # 9 have also provided the evaluation of parameters which simulate very well rod mill product size distributions, and all three groups of functions can certainly be used to simulate the rod mill adequately.

Searches carried out while assuming no particular shape for the selection function lead as a group to a better fit between rod mill corresponding observed and simulated product size distributions. The general trend of these discretized selectionsfunctions is as expected,

TABLE V - SUMMARY OF SEARCHES CONDITIONS - SIMULATION ACCURACY RESULTS

| Search # | Breakage function | Selection function | Sum of Squared deviations |
|---|---|---|---|
| 1 | Calculated industrial pr. mill H.S. | Linear log/log plot | $10.019 \times 10^{-3}$ |
| 2 | Calculated industrial sec. mill H.S. | Linear log/log plot | $13.221 \times 10^{-3}$ |
| 3 | B - C)μ * | Linear log/log plot | $6.0087 \times 10^{-3}$ |
| 4 | B - C)μ | Curvilinear log/log plot $2^{\delta}$ (the curvature is not taken) | $6.0087 \times 10^{-3}$ |
| 5 | B - C)μ | Curvilinear log/log plot $3^{\delta}$ (the curvature is not taken) | $6.008 \times 10^{-3}$ |
| 6 | B - C)μ | Curvilinear log/log plot $3^{\delta}$ | $6.248 \times 10^{-3}$ |
| 7 | Experimental laboratory 16"Ø mill | Discretized | $3.93 \times 10^{-3}$ |
| 8 | Experimental laboratory 11"Ø mill | Discretized | $3.89 \times 10^{-3}$ |
| 9 | B - C)μ | Discretized | $3.98 \times 10^{-3}$ |
| 10 | B - C ** | Discretized | $4.71 \times 10^{-3}$ |

| Search # | Breakage function | Selection function | Sum of Squared deviations |
|---|---|---|---|
| 11 | B - C)μ (product of initial size permitted) | Discretized | $4.45 \times 10^{-3}$ |
| 12 | Calculated industrial pr. mill H.S. | Discretized | $3.90 \times 10^{-3}$ |

---

* Broadbent-Callcott function with optimizable μ

** Original Broadbent-Callcott function

that is the value of the S function is generally decreasing with particle size (see figure 14). For particle size smaller than about ten times the maximum size, the selection can deviate strongly from the general trend; these deviations are however considered to have no physical significance. Figure 10 shows a direct comparison between discretized selection functions and corresponding linear selection function.

No conclusions can be drawn on the effect of using breakage functions which allow or do not allow, upon breakage of original size particle, the presence of original size particles in the product. The values of the sum of squared deviations for search pair # 5 and # 6 and search pair # 10 and # 11 are an illustration of this point.

For the relationship between the feed, the number of stages of breakage and the mill constant, Lynch suggests the following equation:

$$Q\, v^{\gamma} = K$$

The value for Q, the feed rate can be expressed in tons per hour for the ore or in terms of a volumetric flow of pulp in cubic meters per hour. The power of v, the number of stages of breakage is usually taken as 1.5. For the Heath Steele mill, a value of 1.5 provides the best ajustment for the various shapes used for B and S. Others have used apparently successfully a value of 1.0 for v (7).

An examination of feed rates and feed size distributions observed at Heath Steele shows that the feed rate influences the grinding. However, the transport properties within the mill are also a function of the proportion of water in the pulp. It can be expected that the mill product will be influenced by the total pulp flow rate to the mill.

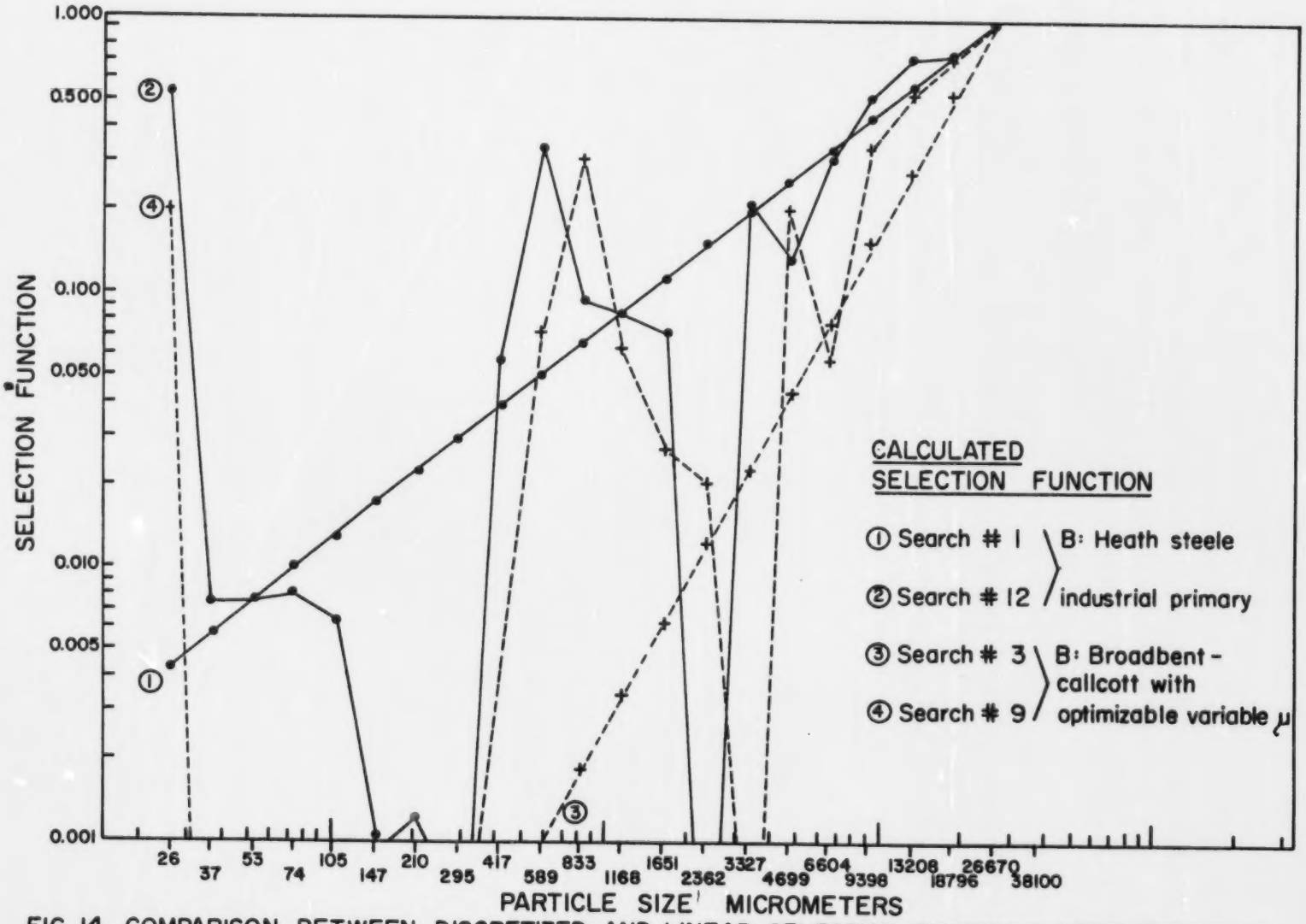



FIG. 14 COMPARISON BETWEEN DISCRETIZED AND LINEAR SELECTION FUNCTIONS USING TWO DIFFERENT BREAKAGE FUNCTIONS

However, as the Heath Steele mill operates at essentially a constant percent solids and being that the relationship between the number of breakage stage and the feed rate is empirical, only the differences in feed rate of ore in tons per hour need be considered.

Following the previous discussions, the values of suggested Heath Steele rod mill parameters for simulation are given in table VI; they correspond to the values used and calculated for search # 8; equivalent values for searches # 7 and # 9 could also certainly be used.

TABLE VI - SUGGESTED HEATH STEELE ROD MILL PARAMETERS FOR SIMULATION

A. Breakage function:

B < 1.0, 0.563, 0.357, 0.268, 0.209, 0.167, 0.134, 0.107, 0.088, 0.071, 0.058, 0.045, 0.0371, 0.0299, 0.0242, 0.0194, 0.0158, 0.0127, 0.0103, 0.0083, 0.0065, 0.0 >

. No product of initial size after breakage.
. Assumed normalisable.
. As determined from laboratory batch grinding in a 11-inch diameter mill (6).

B. Selection function:

S < 1.00, 0.839, 0.730, 0.602, 0.321, 0.457, 0.167, 0.242, 0.198, 0.110, 0.305, 0.357, 0.419, $0.223 \times 10^{-4}$, $0.158 \times 10^{-16}$, $0.422 \times 10^{-17}$, $0.138 \times 10^{-17}$, $0.734 \times 10^{-18}$, $0.206 \times 10^{-18}$, $0.999 \times 10^{-4}$, 0.815, 0.0 >

. As evaluated through optimization technique presented in the report.

C. Classification function:

C < 1.0, 0.0, 0.0 ... 0.0 >

D. Mill constant:

$K = 1530$ with $Qv^{1.5} = K$

where Q is the feed rate in tons per hour and v is the breakage stage.

## B. EVALUATION OF A COMBINED ROD MILLING/GRINDING CIRCUIT SIMULATOR

In order to evaluate the influence of inaccuracies introduced by the rod mill model on the Heath Steele Mines grinding simulator CIRCUITHS results, the rod mill model was added and simulation tests were carried out with two sets of rod mill functions corresponding respectively to search # 9 (one of the best set of functions), rod mill model # 1, and search # 2 (the worst set of functions), rod mill model # 2. The two classification models were considered with the model previously established (2): one without constraints and another with fixed Rf and $Q_{50}$. Appendix 2 gives detailed calculations results while a summary of results is presented in table VII.

On an average basis, the introduction of a new element in the simulator (the rod mill model) increases slightly the deviation between experimental and calculated variables. For minus 270 mesh, the biases introduced by rod mill modelling are generally transmitted to primary and secondary cyclone overflows. The differences between results obtained with cyclone modelling procedure # 1 and # 2 are small. This is an indication that the cyclone model does not introduce a supplementary bias. The rod mill model II gives, as expected, stronger deviations but these deviations can be considered as reasonable. Figure 15 shows the quality of the prediction of circulating load ratios: it appears that the performance of the rod mill model II is slightly worse than that the model I, but is however acceptable. For test run # 3, the comparison of the two modelling procedures of the rod mill is represented in figure 16 for the particle size distributions of rod mill discharge, primary and secondary cyclone overflows. This confirms that model I is better than model II and however that the two models are satisfying.

TABLE VII - SUMMARY OF CIRCUITHS (WITH ROD MILL MODEL) SIMULATION RESULTS

| Test Run | Circuit | Absolute Value of Deviation % - 270 mesh | | | Circulating Load Ratio | | Corrected Cut Sizes | | Watersplit Coefficients | | Cyclone Modelling |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | RMD | PCOF | SCOF | CIRP | CIRS | $d_{50}P$ | $d_{50}S$ | RfP | RfS | CL |
| 1 | EXP | 0 | 0 | 0 | 3.00 | 3.40 | 190 | 52 | 46.4 | 26.3 | |
| | P.S | | 1.5 | 0.7 | 3.16 | 3.54 | 190 | 52 | 46.4 | 26.3 | 2 |
| | | | 1.7 | 0.7 | 3.01 | 3.45 | 198 | 53 | 47.4 | 26.6 | 1 |
| | R.P.S.1 | 3.5 | 4.8 | 4.3 | 3.23 | 3.84 | 190 | 52 | 46.4 | 26.3 | 2 |
| | | | 5.1 | 4.6 | 3.15 | 3.71 | 201.4 | 53.5 | 48.1 | 27.2 | 1 |
| | R.P.S.2 | 5.6 | 7.1 | 6.0 | 3.23 | 4.20 | 190 | 52 | 46.4 | 26.3 | 2 |
| | | | 7.4 | 6.3 | 3.14 | 4.02 | 200.4 | 54 | 47.9 | 27.9 | 1 |
| 2 | EXP | 0 | 0 | 0 | 2.04 | 2.49 | 166 | 53.5 | 35.1 | 24.6 | |
| | P.S | | 0.12 | 2.2 | 2.05 | 2.51 | 166 | 53.5 | 35.1 | 24.6 | 2 |
| | | | 0.9 | 1.9 | 2.35 | 2.68 | 161 | 52.5 | 37.2 | 24.1 | 1 |
| | R.P.S.1 | 0.33 | 0.5 | 1.8 | 2.02 | 2.49 | 166 | 53.5 | 35.1 | 24.6 | 2 |
| | | | 1.1 | 1.6 | 2.29 | 2.65 | 159.4 | 52.4 | 36.7 | 24.3 | 1 |
| | R.P.S.2 | 2.7 | 3.0 | 0.12 | 2.04 | 2.74 | 166 | 53.5 | 35.1 | 24.6 | 2 |
| | | | 3.7 | 0.32 | 2.33 | 2.90 | 160.6 | 52.9 | 37.1 | 25.0 | 1 |
| 3 | EXP | 0 | 0 | 0 | 1.89 | 2.02 | 128 | 50 | 27.6 | 21.3 | |
| | P.S | | 0.5 | 1.0 | 1.87 | 1.91 | 128 | 50 | 27.6 | 21.3 | 2 |
| | | | 0.7 | 1.0 | 1.79 | 1.94 | 134 | 49.8 | 28.5 | 21.5 | 1 |
| | R.P.S.1 | 0.84 | 1.7 | 1.9 | 1.84 | 1.98 | 128 | 50 | 27.6 | 21.3 | 2 |
| | | | 1.8 | 2.0 | 1.77 | 2.0 | 133 | 50 | 28.3 | 21.6 | 1 |
| | R.P.S.2 | 3.8 | 4.9 | 4.04 | 1.89 | 2.19 | 128 | 50 | 27.6 | 21.3 | 2 |
| | | | 5.0 | 4.2 | 1.80 | 2.19 | 134 | 50.5 | 28.6 | 22.2 | 1 |
| 4 | EXP | 0 | 0 | 0 | 1.58 | 1.69 | 120 | 50 | 24.9 | 19.2 | |
| | P.S | | 3.8 | 2.0 | 1.44 | 1.47 | 120 | 50 | 24.9 | 19.2 | 2 |
| | | | 4.1 | 2.2 | 1.41 | 1.45 | 116 | 49.7 | 22.2 | 18.6 | 1 |
| | R.P.S.1 | 0.3 | 4.9 | 2.8 | 1.45 | 1.42 | 120 | 50 | 24.9 | 19.2 | 2 |
| | | | 5.3 | 3.1 | 1.42 | 1.40 | 116.5 | 49.5 | 22.3 | 18.4 | 1 |
| | R.P.S.2 | 1.6 | 2.4 | 1.2 | 1.42 | 1.52 | 120 | 50 | 24.9 | 19.2 | 2 |
| | | | 2.9 | 1.4 | 1.4 | 1.49 | 115.5 | 49.8 | 22.0 | 18.7 | 1 |

EXP: Experimental results. P.S: Ball mill circuit simulation.

R.P.S.1: Ball mill circuit simulation with rod mill model # 1 (B: Broadbent-Callcott $\mu$ + S discretized).

R.P.S.2: Ball mill circuit simulation with rod mill model # 2 (B: experimental + S linear log/log plot).

CL 1: Classification model without constraints. CL 2: Classification model with fixed Rf and $d_{50}$.

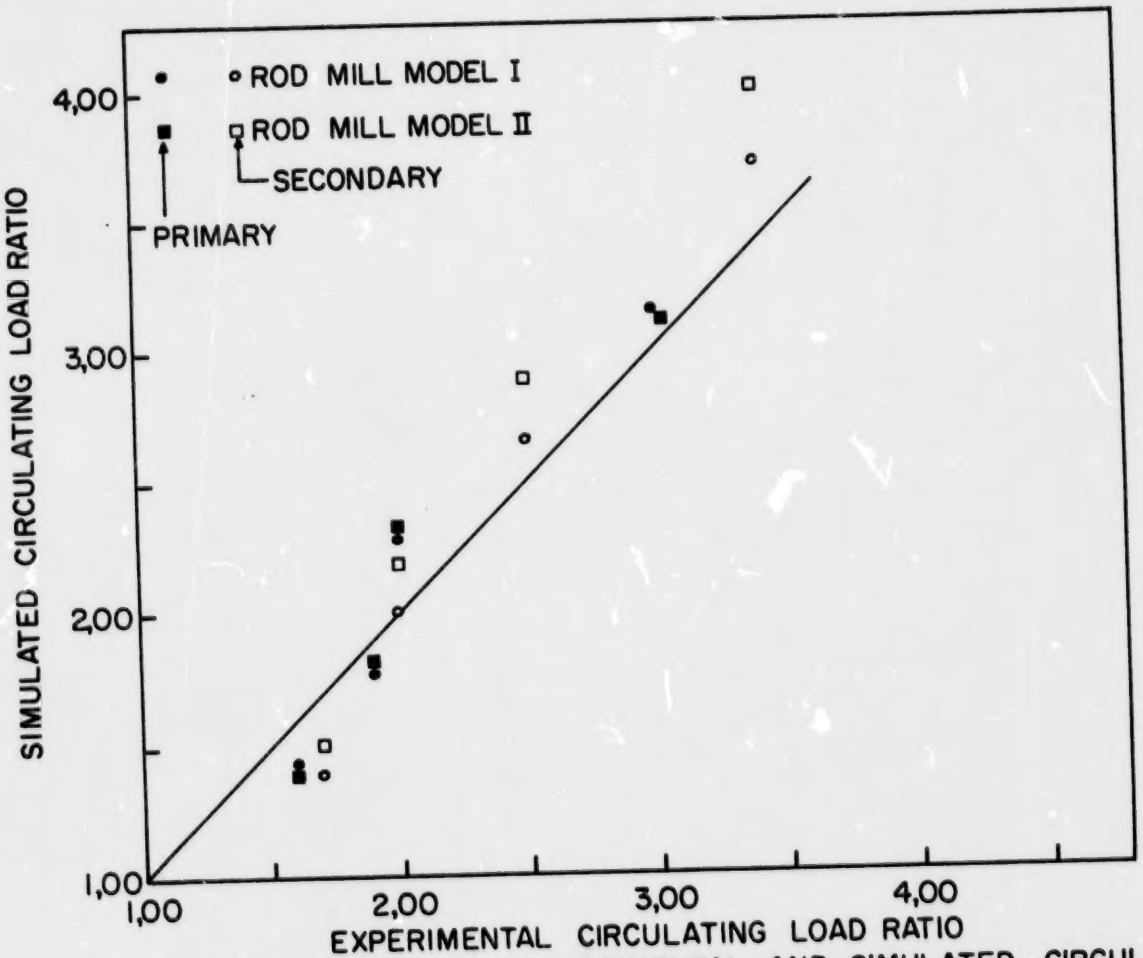



FIG. 15 COMPARISON BETWEEN EXPERIMENTAL AND SIMULATED CIRCULATING LOAD RATIOS USING SIMULATION CIRCUIT HS AND 2 DIFFERENT ROD MILL MODELS.

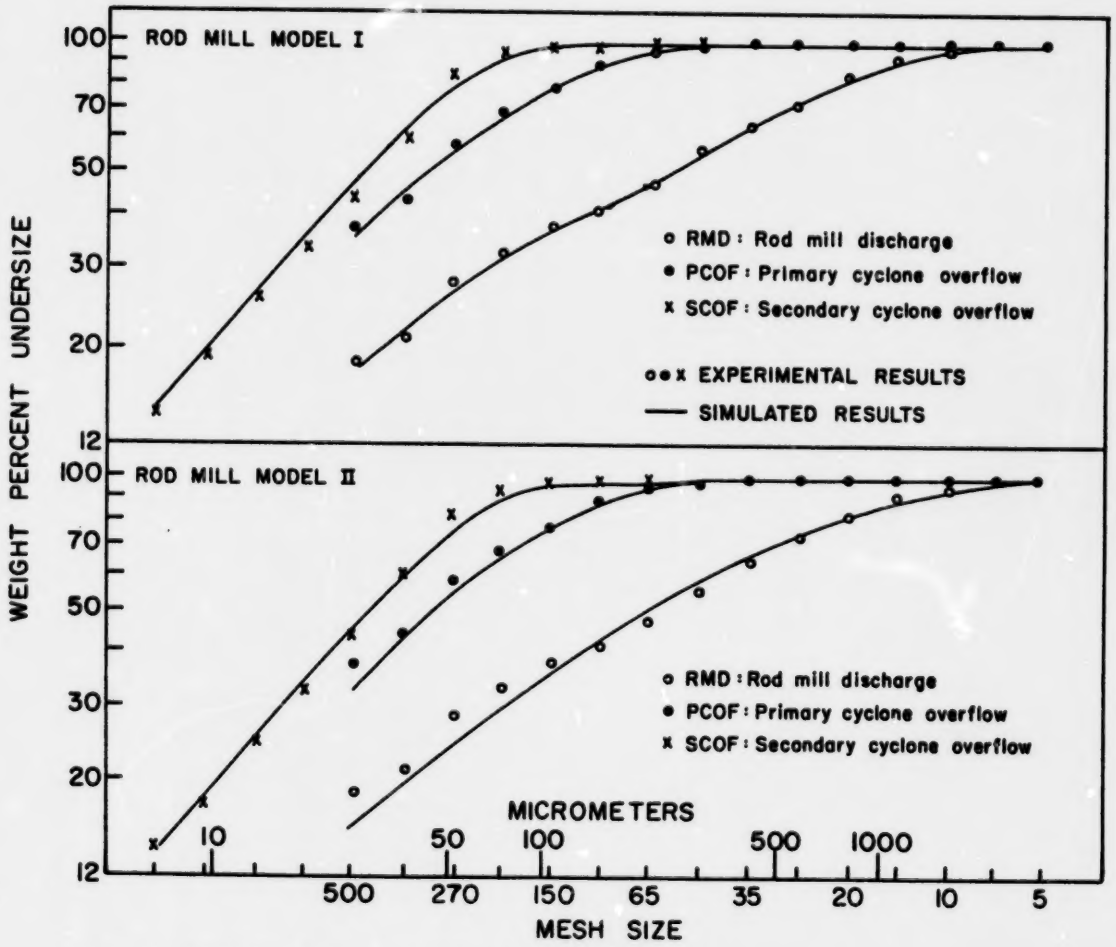



FIG. 16 COMPARISON BETWEEN EXPERIMENTAL AND SIMULATED SIZE DISTRIBUTIONS, RUN #3 USING SIMULATOR CIRCUITHS WITH 2 DIFFERENT ROD MILL MODELS.

# CONCLUSIONS

Using the experimental data for 4 test runs performed on the Heath Steele rod milling process, a model have been identified and incorporated in previous grinding circuit simulator of the two stages of ball milling. The main results are summarized as follows.

## Modelling

The model uses the stage of breakage concept to describe the behavior of the rod mill. Various breakage and selection functions representation have been tried to apply this model. The following conclusions can be set up:

- the discharge size distributions are generally adequately predicted by the model.
- the relationship between feed rate and kinetics works satisfactorily.
- the physical sense of the model and its parameter is somewhat questionable:
    - practicallythe model with simplified classification does not take into account the selective transport that occurs in a rod mill, since it is formally identical to a simplified one without classification.
    - the model takes into account the variation of kinetics along the rod mill axis but in a rather arbitrary manner.

Identification of parameters

A least squares technique has been used to identified the parameters: breakage function, selection function and mill constant. The main conclusions are:

- The agreement between experimental and calculated size distributions is better when selection function is discretized rather than described by a log/log polynom (mean absolute standard error on mass fraction of approximately 0.010 against 0.015)

- The simultaneous identification of breakage and selection functions leads to very different results depending on the representation hypotheses. The coupling of these two parameters seems to be stronger than for ball mill parameters identification and it is recommended, when possible, to use an experimental breakage function in order to ascertain a physical meaning to the selection function.

Simulation of complete circuit

The rod mill model has been incorporated in the Heath Steele grinding circuit simulation. As a consequence the product delivered by the secondary cyclo-pack can be predicted knowing the ore feed rate and the size distribution to rod mill feed and the various flow rates of water added to the circuit. Various simulations have been performed and it is concluded that the simulator works very well, and will be a very robust and useful tool for subsequent studies.

REFERENCES

1) D. Hodouin, M.A. Bérubé and M.D. Everell, "Report on the Sampling Campaign Performed on the Grinding Circuit of Heath Steele Mines Ltd (N.B.) during March 1977, Research Report submitted to CANMET by GRAAIM, Laval University, July, 1977.

2) D. Hodouin, M.A. Bérubé, J.C. Marchand, J. McMullen and M.D. Everell, "Modelling of the Heath Steele Mines Hydrocyclones and Ball Mills", Research Report 78-5, submitted to CANMET by GRAAIM, Laval University, November, 1978.

3) D. Hodouin, M.A. Bérubé, J. McMullen and M.D. Everell, "Development of a simulator of the Heath Steele Mines Grinding Circuit", Research Report 78-6 submitted to CANMET by GRAAIM, Laval University, November, 1978.

4) A.J. Lynch, "Mineral Crushing and Grinding Circuits: Their Simulation, Optimization, Design and Control", Vol. 1 pp. 51-60, Elsevier Scientific Publishing Company, 1977.

5) T.G.Callcott and A.J. Lynch, "An Analysis of Breakage Processes Within Rod Mills", Australasian Inst. of Mining and Metall., no. 209, 1964.

6) D. Hodouin, M.A. Bérubé et M.D. Everell, "Etude des paramètres des modèles mathématiques utilisés pour simuler le processus de broyage", Revue de l'Industrie Minérale, Minéralurgie, Février, 1979.

7) D. Hodouin, J. McMullen and M.D. Everell, "A Study of the Wet Batch Grinding of the Heath Steele Mines Ore, in a Pilot Ball Mill, Research Report # 79-3 submitted to CANMET by GRAAIM, Laval University, April, 1979.

8) M.J. Allen, L. Hamel, S.J. Miller and A.L. Mular, "Digital Simulation of the Gibraltar Grinding Circuit", Presented at the Annual Meeting of the Canadian Institute of Mining and Metallurgy, Vancouver, April, 1973.

# APPENDIX I

## APL PROGRAMS USED TO CALCULATE BREAKAGE AND SELECTION FUNCTIONS OF A ROD MILL

Of the programs used, POWELL and BOTM were taken from a book entitled "Optimization Techniques with Fortran" by J.L. Kuester and J.H. Mize and translated to APL language. Other programs were written to permit calculation of the rod mill parameters; they are: CALCFX, MATX, CPR, CALB, CABLY and SELTN.

CALCFX is a sub-program in BOTM which must be defined for each particular problem; here it uses optimization variables X to permit rod mill calculations. Data necessary are those of sub-program MATX.

MATX calculates grinding matrix Zi of the i th breakage stage and corresponding final product size distributions.

Input data are:

- FBA: the vector for observed size distributions.
- PB: the vector for the corresponding observed product size distributions.
- Q: the vector for ore feed rates in weight or in volume corresponding to observed feeds and products. Q can also be a slurry flow rate to the mill when it is possible to take into account the water feed rate.
- XT: the vector of screen size openings in micrometers.
- Initial values for the X vector of optimization variables in POWELL. X contains generally constant K of equation $Q.v^{1.5} = K$ for the number of breaking stages, exponent $\mu$

of the cumulative breakage function equation ;
$GB = 1 - e^{-(x/y)_{\mu}}/(1 - e^{-1})$, coefficients $a_1$, $a_2$, $a_3$ of the selection function equation.
$S = e^{a} + a_1(\ln x) + a_2(\ln x)^2 + a_3(\ln x)^3$
X can obviously be constructed according to the choice of Q, GB or S.

The sub-programs are: CPR, CALB (or CALBLY), SELTN.

CPR calculates the breakage matrix of the first stage when a classification vector C= 1, 0, 0 ...0 is selected. It is a sub-program of MATX which requires the external definition of the triangular non-cumulative breakage matrix B, elements of the selection function S, classification vector C and diagonal elements of unit matrix UN.

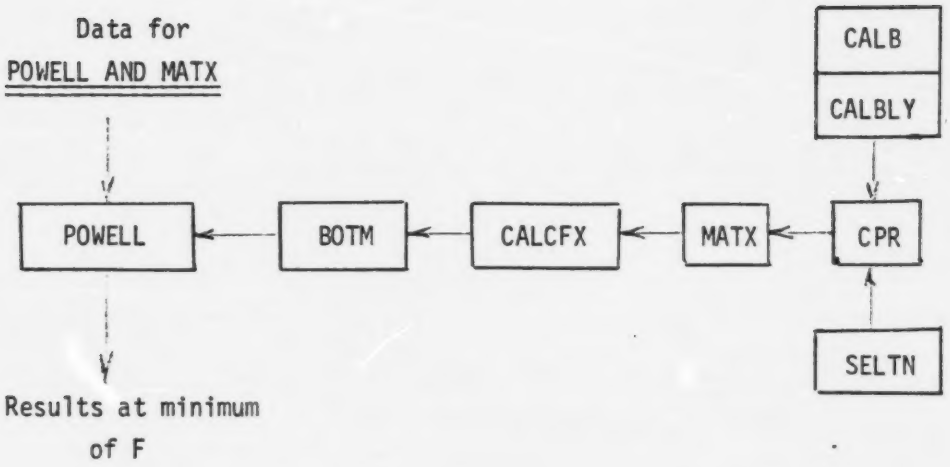
CALB constructs a triangular matrix B when GB and N the size of the problem are defined externally.

CALBLY constructs a triangular matrix B, in the same manner as CALB when the function GB used allows the presence of daughter fragments of original particle size. The size of fragments XT must be adjusted in order to calculate function GB correctly whether we select for the original size the geometric average of the largest particles in the feed or simply their size interval.

SELTN calculates the selection function S when vectors XT and coefficients $a_1$, $a_2$ and $a_3$ are defined externally.

Logic diagram of programs and APL listings are given in the following pages.

Logic diagram of programs



```
    ▼ MATX;B;C;F1;I;J;K;PC;PCP;UN;N;Y;Z
[1]   PC←0,1↓C←1,(N-1)⍴0,⍬UN←N⍴1,⍬N←1+⍴XT,⍬I←J←1,⍬V←((⍴FBA)÷(1+⍴XT))⍴0
[2]   GB←GB16
[3]   CALB
[4]   SELTN
[5]   S←S,0,⍬K←X[1],⍬⍬BC←10
[6]  L1:Y←V[J]-LV[J]←(K÷Q[J])*2÷3
[7]   →(J>1)/L11
[8]   CPR
[9]  L11:Z←Z1
[10]  PC←(N×J-1)↓(N×J)↑FBA,⍬I←1
[11] L2:PC←Z+.×PC
[12]  Z[(N-1)↑]←(1,N)⍴+/[1]Z[(N-1),N↑]
[13]  Z←(N⍴0),[2]Z←((N-1)⍴0),[1]Z←¯1 ¯1↓Z
[14]  →(I≤LV[J])/L2,⍬I←I+1
[15]  PCP←Z+.×PC
[16]  PBC←PBC,PC←((1-Y)×PC)+Y×PCP
[17]  →(J≤((⍴FBA)÷(1+⍴XT)))/L1,⍬J←J+1
[18]  F←+/(PBC-PB)*2
    ▼

    ▼ CPR;I;IJ;IP;ZD;UNP;SI
[1]   ZD←(N,N)⍴0,⍬Z1←(N,N)⍴0,⍬I←IP←IJ←1
[2]   SI←UN-S
[3]  L1:ZD[;IP]←B[;IP]×S[IP]
[4]   →(N≥IP←IP+1)/L1,⍬ZD[IP;IP]←SI[IP]+ZD[IP;IP]
[5]   UNP←÷UN-ZD[1;1],(N-1)⍴0
[6]   ZD[1;1]←0
[7]   →(N≥IJ←IJ+1)/⎕LC[1],⍬Z1[;IJ]←ZD[;IJ]×UNP[IJ]
    ▼

    ▼ SELTN
[1]   T1←(⍟XT÷XT[1]),⍬T2←(⍟XT÷XT[1])×(⍟XT×XT[1]),⍬T3←((⍟XT)*3)-(⍟XT[1])*3
[2]   S←*(X[2]×T1)+(X[3]×T2)+(X[4]×T3)
    ▼

    ▼ CALB
[1]   B[N;]←(1,N)⍴1↓⌽0,GB,⍬B←((⍳N)∘.>⍳N)×(1-⍳N)⌽(N,N)⍴0,(¯1↓GB)-1↓GB
    ▼



    ▼ CALBLY
[1]   B[N;]←(1,N)⍴⌽GB,⍬B←(((⍳N-1),(N-1))∘.≥⍳N)×(1-⍳N)⌽(N,N)⍴((¯1↓GB)-(1↓GB)),GB[N
    ▼

    ▼ F←CALCFX;S
[1]   MATX
    ▼
```

```
     ▼ CPR;I;IJ;IP;ZD;UNP;SI
[1]    ZD←(N,N)⍴0,0⍴Z1←(N,N)⍴0,0⍴I←IP←IJ←1
[2]    SI←UN-S
[3]   L1:ZD[;IP]←B[;IP]×S[IP]
[4]    →(N≥IP←IP+1)/L1,0⍴ZD[IP;IP]←SI[IP]+ZD[IP;IP]
[5]    UNP←÷UN-ZD[1;1],(N-1)⍴0
[6]    ZD[1;1]←0
[7]    →(N≥IJ←IJ+1)/□LC[1],0⍴Z1[;IJ]←ZD[;IJ]×UNP[IJ]
     ▼

     ▼ SELTN
[1]    T1←(⊛XT÷XT[1]),0⍴T2←(⊛XT÷XT[1])×(⊛XT×XT[1]),0⍴T3←((⊛XT)*3)-(⊛XT[1])*3
[2]    S←+(X[2]×T1)+(X[3]×T2)+(X[4]×T3)
     ▼

     ▼ CALB
[1]    B[N;]←(1,N)⍴1↓⌽0,GB,0⍴B←((⍳N)∘.>⍳N)×(1-⍳N)⊖⍉(N,N)⍴0,(¯1↓GB)-1↓GB
     ▼

     ▼ CALBLY
[1]    B[N;]←(1,N)⍴⌽0GB,0⍴B←(((⍳N-1),(N-1))∘.≥⍳N)×(1-⍳N)⊖⍉(N,N)⍴((¯1↓GB)-(1↓GB)),GB[N;
     ▼
```

```
    ▼ F←CALCFX;S
[1]   MATX
    ▼

    ▼ MATX;B;C;F1;I;J;K;PC;PCP;UN;N;Y;Z
[1]   PC←0,1↓C←1,(N-1)⍴0,0⍴UN←N⍴1,0⍴N←1+⍴XT,0⍴I←J←1,0⍴V←((⍴FBA)÷(1+⍴XT))⍴0
[2]   GB←GB16
[3]   CALB
[4]   SELTN
[5]   S←S,0,0⍴K←X[1],0⍴PBC←⍳0
[6]  L1:Y←V[J]-LV[J]←(K÷Q[J])*2÷3
[7]   →(J>1)/L11
[8]   CPR
[9]  L11:Z←Z1
[10]  PC←(N×J-1)↓(N×J)↑FBA,0⍴I←1
[11] L2:PC←Z+.×PC
[12]  Z[(N-1)+⍳N]←(1,N)⍴+/[1]Z[(N-1),N+⍳N]
[13]  Z←(N⍴0),[2]Z←((N-1)⍴0),[1]Z←¯1 ¯1↓Z
[14]  →(I≤LV[J])/L2,0⍴I←I+1
[15]  PCP←Z+.×PC
[16]  PBC←PBC,PC←((1-Y)×PC)+Y×PCP
[17]  →(J≤((⍴FBA)÷(1+⍴XT)))/L1,0⍴J←J+1
[18]  F←+/(PBC-PB)*2
    ▼
```

# APPENDIX II

## CALCULATION WITH CIRCUITHS SIMULATOR (including rod mill)

(with classifier model # 1)

## NOMENCLATURE

1- ROD MILL

Débit: ore feed rate

Constante: K value (units?)

Scalpage: number of size interval fed to the rod mill

Mesh: Tyler mesh

X: micrometers screen aperture

ALB, DECB: Feed and discharge mill size distributions (percent passing mesh size)

B: $B_{il}$ vector.

S: $S_i$ vector for size interval between i and i+ 1 screens apertures.

2- Ball mills

HC (1) to HC (16): coefficients of cyclones models.

RO: ore specific gravity

QE: water flow rate in circuit feed

DE1: water flow rate added to sump box

DE2: water flow rate added to mill feed

PST: fraction of time corresponding to plug flow.

MLP: number of perfect mixers in series.

NC: Number of cyclones

CIR: circulating load ratio
DS: ore flow rate to cyclone feed
RS: mill throughput
QST: ore flow rate from circuit
W: variable not used in this paper
DESU: water flow rate from cyclone overflow
RE: water flow rate from cyclone underflow
DE: water feed rate to cyclone
DEB: water flow rate through ball mill
DV: volumetric flow rate to cyclone
RF: water split coefficient
DENS: ore mass fraction in cyclone feed
DENSO: ore mass fraction in cyclone feed underflow
DENSU: ore mass fraction in cyclone feed overflow
DI50: variable not used in this paper
D50 : corrected cut size
TAU: apparent grinding time
MESH: Tyler mesh
X: $_i$th geometric mean size in the interval between screens i and i 1
ALIM: size distributions of circuit feed
ALBR: size distributions of mill feed
DECBR: size distributions of mill discharge
ALCYC: size distributions of cyclone feed
SURV: size distributions of overflow
C: cyclone efficency
CC: corrected cyclone efficiency
B: $B_{i1}$ vector of cumulative breakage function
S: $S''_i$ value for particle size $oc_i$ from X vector

1. SIMULATION RESULTS USING
ROD MILL MODEL # 1
( with classifier model # 1)

a) Circuit Feed Rate: 87.11 t/h
Rod Mill Data / Model # 1

VARIABLES DE SORTIE

DEBIT= 87.11 CONSTANTE= 1402.00 SCALPAGE= 22.00

| MESH | X | ALIM | PROD | R | S |
|---|---|---|---|---|---|
| 38100 | 38100 | 100.00 | 100.00 | 1.00000 | 1.00000 |
| 26670 | 26670 | 97.20 | 100.00 | 0.64400 | 0.81700 |
| 18796 | 18796 | 84.00 | 100.00 | 0.50900 | 0.70700 |
| 13208 | 13208 | 63.80 | 100.00 | 0.40900 | 0.55900 |
| 9398 | 9398 | 52.30 | 100.00 | 0.33900 | 0.47400 |
| 6604 | 6604 | 41.80 | 100.00 | 0.26400 | 0.37300 |
| 4 | 4699 | 34.00 | 100.00 | 0.21200 | 0.33770 |
| 6 | 3327 | 29.40 | 99.38 | 0.17000 | 0.06690 |
| 8 | 2362 | 25.20 | 97.07 | 0.12700 | 0.11800 |
| 10 | 1651 | 21.30 | 91.84 | 0.11000 | 0.01960 |
| 14 | 1168 | 18.40 | 83.09 | 0.09200 | 0.13700 |
| 20 | 833 | 16.10 | 73.04 | 0.07100 | 0.34100 |
| 28 | 589 | 14.40 | 63.59 | 0.05480 | 0.00212 |
| 35 | 417 | 13.10 | 54.95 | 0.04540 | 0.00024 |
| 48 | 295 | 11.20 | 47.74 | 0.03660 | 0.00041 |
| 65 | 210 | 10.90 | 41.74 | 0.00910 | 0.00012 |
| 100 | 147 | 9.80 | 34.58 | 0.02350 | 0.00068 |
| 150 | 105 | 8.90 | 32.10 | 0.01870 | 0.00000 |
| 200 | 74 | 8.10 | 27.28 | 0.01520 | 0.00000 |
| 270 | 53 | 6.90 | 22.15 | 0.01210 | 0.00000 |
| 400 | 37 | 4.80 | 17.04 | 0.00940 | 0.20500 |
| 500 | 25 | 4.50 | 14.38 | 0.00000 | 0.00000 |

PROJECTION

CIRCUIT PRIMAIRE

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCF1]= | 0.000 | HCF5]= | 0.500 | HCF9]= | 0.950 | HCF13]= | 1.428 | PR = | 3.50 |
| HCF2]= | 0.010 | HCF6]= | 0.842 | HCF10]= | 5.392 | HCF14]= | 2.889 | DR = | 19.23 |
| HCF3]= | 0.001 | HCF7]= | 0.000 | HCF11]= | 2.589 | HCF15]= | 0.023 | QR1= | 0.26 |
| HCF4]= | 1.258 | HCF8]= | -10.710 | HCF12]= | 1.302 | HCF16]= | 0.040 | QR2= | 1.33 |
| | | | | | | | | PST= | 0.100 |
| | | | | | | | | MLP= | 2.600 |
| | | | | | | | | HC = | 1.000 |

VARTABLES DE SORTIE

| | | | |
|---|---|---|---|
| CIR= 3.154 | DESH= 44.230 | DENS =80.95 | D150= 90.22 |
| DS =361.808 | RE = 40.920 | DENSH=97.04 | D50 =201.04 |
| RS =274.708 | DE = 85.150 | DENSH=66.32 | TAU = 0.22 |
| QST= 87.101 | DER = 57.320 | DENSR=82.74 | |
| W = 1.000 | DV =165.552 | | |
| | RF = 48.057 | | |

| MESH | X | AI TM | AI BR | DECBR | AI CYC | SURV | C | CC | R | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 2830 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 17.00 |
| 8 | 2000 | 97.07 | 98.99 | 99.92 | 99.23 | 100.00 | 99.71 | 99.44 | 0.81 | 10.71 |
| 10 | 1410 | 91.84 | 96.95 | 99.53 | 97.68 | 99.98 | 99.17 | 98.46 | 0.65 | 6.75 |
| 14 | 1000 | 83.09 | 92.77 | 98.09 | 94.48 | 99.87 | 98.63 | 97.37 | 0.52 | 4.25 |
| 20 | 707 | 73.04 | 86.20 | 94.61 | 89.42 | 99.58 | 98.05 | 96.25 | 0.42 | 2.68 |
| 28 | 500 | 63.59 | 76.75 | 87.92 | 82.10 | 98.99 | 96.83 | 93.89 | 0.33 | 1.69 |
| 35 | 354 | 54.95 | 63.13 | 76.45 | 71.42 | 97.58 | 93.77 | 88.01 | 0.27 | 1.06 |
| 48 | 250 | 47.76 | 46.11 | 60.78 | 57.65 | 94.02 | 84.25 | 69.47 | 0.21 | 0.67 |
| 65 | 177 | 41.74 | 31.99 | 45.92 | 44.92 | 85.69 | 68.03 | 38.45 | 0.17 | 0.42 |
| 100 | 125 | 36.58 | 24.41 | 36.42 | 36.46 | 74.46 | 57.71 | 18.59 | 0.14 | 0.27 |
| 150 | 88 | 32.10 | 19.72 | 29.71 | 30.28 | 63.61 | 52.78 | 9.09 | 0.11 | 0.17 |
| 200 | 63 | 27.28 | 16.00 | 24.19 | 24.94 | 53.12 | 50.41 | 4.53 | 0.09 | 0.11 |
| 270 | 44 | 22.15 | 12.80 | 19.46 | 20.11 | 43.19 | 49.03 | 1.88 | 0.07 | 0.07 |
| 400 | 31 | 17.04 | 9.83 | 15.03 | 15.51 | 33.45 | 48.27 | 0.40 | 0.05 | 0.04 |
| 500 | 22 | 14.38 | 7.96 | 11.99 | 12.52 | 27.12 | 48.06 | 0.00 | 0.00 | 0.00 |



Model # 1

RESULTATS

CIRCUIT SECONDAIRE

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCE11= | 0.000 | HCF51= | 0.230 | HCE91 = | 0.965 | HCF131= | 1.406 | MU = | 4.50 |
| HCE21= | 0.003 | HCF61= | 0.076 | HCF101= | 5.674 | HCF141= | 2.268 | DE = | 44.23 |
| HCE31= | 0.000 | HCF71= | 0.000 | HCF111= | 2.738 | HCF151= | 0.000 | DE1= | 136.90 |
| HCE41= | 1.542 | HCF81= | -4.430 | HCF121= | 1.778 | HCF161= | 0.000 | DE2= | 13.80 |
| | | | | | | | | RST= | 0.100 |
| | | | | | | | | MUP= | 2.500 |
| | | | | | | | | NF = | 3.000 |

VARIABLES DE SORTIE

| | | | | |
|---|---|---|---|---|
| CIR= 3.709 | DESU=194.230 | DENS =60.59 | D150=151.96 | |
| DS =410.159 | RE = 72.600 | DENSD=81.65 | D50 = 53.46 | |
| RS =323.058 | DF =266.830 | DENSH=30.96 | TAU = 0.19 | |
| QST= 87.100 | DER = 86.400 | DENSR=78.90 | | |
| W = 1.000 | DV =357.977 | | | |
| | RF = 27.208 | | | |

| MESH | X | ALIM | ALBR | DECBR | ALCYC | SHRU | P | CC | R | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 707 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 12.88 |
| 28 | 500 | 98.99 | 99.67 | 99.95 | 99.74 | 100.00 | 97.35 | 96.50 | 0.56 | 7.20 |
| 35 | 354 | 97.58 | 99.08 | 99.71 | 99.26 | 99.94 | 97.45 | 96.50 | 0.43 | 4.61 |
| 48 | 250 | 94.02 | 97.10 | 98.64 | 97.66 | 99.75 | 97.45 | 96.50 | 0.33 | 2.78 |
| 65 | 177 | 85.69 | 90.46 | 94.09 | 92.30 | 99.11 | 97.38 | 96.40 | 0.25 | 1.65 |
| 100 | 125 | 74.46 | 75.56 | 81.30 | 80.24 | 97.62 | 96.37 | 95.01 | 0.19 | 0.99 |
| 150 | 88 | 63.61 | 50.79 | 59.02 | 60.00 | 94.15 | 90.50 | 86.94 | 0.15 | 0.59 |
| 200 | 63 | 53.12 | 24.42 | 32.72 | 37.05 | 83.88 | 74.90 | 65.52 | 0.11 | 0.35 |
| 270 | 44 | 43.18 | 11.56 | 18.23 | 23.53 | 67.90 | 52.32 | 34.50 | 0.08 | 0.21 |
| 400 | 31 | 33.45 | 6.66 | 11.48 | 16.18 | 51.33 | 40.19 | 17.83 | 0.06 | 0.13 |
| 500 | 22 | 27.12 | 4.59 | 8.03 | 12.09 | 39.90 | 33.87 | 9.16 | 0.04 | 0.08 |
| 1 | 16 | 20.25 | 3.13 | 5.50 | 8.20 | 29.37 | 30.60 | 4.66 | 0.03 | 0.05 |
| 2 | 11 | 15.12 | 2.21 | 3.96 | 6.33 | 21.60 | 28.34 | 1.55 | 0.02 | 0.03 |
| 3 | 8 | 11.29 | 1.60 | 2.84 | 4.89 | 15.89 | 27.21 | 0.00 | 0.01 | 0.02 |
| 4 | 5 | 8.43 | 1.18 | 2.06 | 3.81 | 11.69 | 27.21 | 0.00 | 0.00 | 0.00 |



Model # 1

b) Circuit Feed Rate: 79.40 t/h

Rod Mill Data / Model # 1

---

VARIABLES DE SORTIE

DEBIT= 79.40 CONSTANTE= 1443.00 SCALPAGE= 32.00

| MESH | X | ALR | DCDR | R | S |
|---|---|---|---|---|---|
| 3810 | 3810 | 100.00 | 100.00 | 1.00000 | 1.00000 |
| 2667 | 2667 | 97.70 | 100.00 | 0.83800 | 0.81700 |
| 1879 | 1879 | 91.20 | 100.00 | 0.50900 | 0.70700 |
| 1320 | 1320 | 57.10 | 100.00 | 0.40900 | 0.55900 |
| 939 | 939 | 44.40 | 100.00 | 0.32900 | 0.37300 |
| 660 | 660 | 37.00 | 100.00 | 0.24400 | 0.27700 |
| 469 | 469 | 30.40 | 100.00 | 0.21200 | 0.15770 |
| 331 | 331 | 26.10 | 99.90 | 0.17000 | 0.06600 |
| 232 | 232 | 22.90 | 98.57 | 0.13700 | 0.11800 |
| 165 | 165 | 19.60 | 98.91 | 0.11000 | 0.01960 |
| 117 | 117 | 17.10 | 97.62 | 0.08900 | 0.19700 |
| 83 | 83 | 14.90 | 77.29 | 0.07100 | 0.43100 |
| 59 | 59 | 13.30 | 67.89 | 0.05680 | 0.00319 |
| 41 | 41 | 12.10 | 58.46 | 0.04560 | 0.00024 |
| 29 | 29 | 11.10 | 50.61 | 0.03660 | 0.00641 |
| 21 | 21 | 10.20 | 44.19 | 0.02910 | 0.00012 |
| 15 | 15 | 9.30 | 38.54 | 0.02350 | 0.00068 |
| 10 | 10 | 8.50 | 34.00 | 0.01870 | 0.00000 |
| 7 | 7 | 7.70 | 29.30 | 0.01520 | 0.00000 |
| 5 | 5 | 6.90 | 24.05 | 0.01210 | 0.00000 |
| 4 | 3 | 5.10 | 18.87 | 0.00940 | 0.20500 |
| 2 | 2 | 2.40 | 15.74 | 0.00000 | 0.00000 |

RESULTATS

CIRCUIT PRIMAIRE.

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCF11= | 0.000 | HCC53= | 0.330 | HC191 = | 0.950 | HCC137= | 1.478 | KO = | 4.50 |
| HCC21= | 0.010 | HCF63= | 0.042 | HCF101= | 5.396 | HCF141= | 2.889 | DE = | 18.95 |
| HCF31= | 0.001 | HCF73= | 0.000 | HCF111= | 2.589 | HCC151= | 0.024 | DE1= | 6.80 |
| HCF41= | 1.258 | HCF81= | 10.710 | HC1121= | 1.402 | HCF161= | 0.030 | DE2= | 12.00 |
| | | | | | | | | FST= | 0.100 |
| | | | | | | | | MLP= | 2.600 |
| | | | | | | | | NC = | 1.000 |

VARIABLES DE SORTIE

| | | | |
|---|---|---|---|
| CIR= 2.293 | DESU= 42.750 | DENS =79.46 | D150= 78.63 |
| DS =261.453 | RE = 24.822 | DENSO=88.00 | D50 =159.38 |
| RS =182.063 | DE = 67.572 | DENSH=65.00 | TAU = 0.46 |
| QST= 79.390 | DER = 41.822 | DENSR=81.32 | |
| W = 1.000 | DV =125.673 | | |
| | RF = 36.734 | | |

| MESH | X | ALTM | ALBR | DECBR | ALCYC | SURV | C | CC | R | S |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6.2830 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 23.55 |
| | 8.2000 | 98.57 | 99.37 | 99.99 | 99.54 | 100.00 | 100.00 | 100.00 | 0.81 | 14.83 |
| 10 | 1410 | 94.91 | 97.68 | 99.90 | 98.39 | 100.00 | 99.43 | 99.09 | 0.65 | 9.35 |
| 14 | 1000 | 87.62 | 94.04 | 99.42 | 95.84 | 99.95 | 98.77 | 98.06 | 0.52 | 5.89 |
| 20 | 707 | 77.28 | 87.97 | 97.78 | 91.55 | 99.78 | 98.11 | 97.02 | 0.42 | 3.71 |
| 28 | 500 | 67.80 | 80.42 | 94.23 | 86.20 | 99.45 | 97.33 | 95.79 | 0.33 | 2.34 |
| 35 | 354 | 58.46 | 69.59 | 87.17 | 78.45 | 98.77 | 95.46 | 92.83 | 0.27 | 1.48 |
| 48 | 250 | 50.61 | 55.20 | 75.52 | 67.96 | 97.20 | 89.65 | 83.65 | 0.21 | 0.93 |
| 65 | 177 | 44.19 | 38.82 | 60.04 | 55.23 | 92.86 | 74.82 | 60.20 | 0.17 | 0.59 |
| 100 | 125 | 38.54 | 26.73 | 46.35 | 43.97 | 83.53 | 55.82 | 30.17 | 0.14 | 0.37 |
| 150 | 88 | 34.00 | 20.59 | 37.33 | 36.32 | 72.40 | 45.95 | 14.57 | 0.11 | 0.23 |
| 200 | 63 | 29.40 | 16.47 | 30.37 | 30.08 | 61.28 | 41.41 | 7.39 | 0.09 | 0.15 |
| 270 | 44 | 24.06 | 13.05 | 24.45 | 24.33 | 50.19 | 38.89 | 3.41 | 0.07 | 0.09 |
| 400 | 31 | 18.87 | 10.05 | 18.99 | 18.95 | 39.37 | 37.56 | 1.30 | 0.05 | 0.06 |
| 500 | 22 | 15.74 | 8.04 | 15.01 | 15.23 | 31.72 | 36.77 | 0.06 | 0.00 | 0.00 |



Model 1

RESULTATS

CIRCUIT SECONDAIRE

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCF1]= | 0.000 | HCF5]= | 0.240 | HCF9]= | 0.965 | HCF13]= | 1.306 | KD = | 4.50 |
| HCF2]= | 0.003 | HCF6]= | 0.076 | HCF10]= | 5.323 | HCF14]= | 2.231 | DF = | 42.25 |
| HCF3]= | 0.000 | HCF7]= | 0.000 | HCF11]= | 2.738 | HCF15]= | 0.000 | HCF=106.77 | |
| HCF4]= | 1.532 | HCF8]= | 4.430 | HCF12]= | 1.778 | HCF16]= | 0.000 | LE2= | 10.65 |
| | | | | | | | | FST= | 0.100 |
| | | | | | | | | NU= | 2.600 |
| | | | | | | | | DF = | 3.000 |

VARIABLES DE SORTIE

| | | | |
|---|---|---|---|
| CTR= 2.646 | DESH=159.570 | DENS =57.88 | D150=140.79 |
| DS =289.501 | RE = 51.114 | DENSO=80.33 | D50 = 52.39 |
| RS =210.110 | DF =210.684 | DENSH=33.23 | TAU = 0.29 |
| DST= 79.391 | DEB = 41.164 | DENSH=22.45 | |
| W = 1.000 | DU =275.017 | | |
| | RF = 24.261 | | |

| MESH | X | ALTM | ALBR | DECBR | ALCYC | SURU | C | CT | R | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 707 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 12.88 |
| 28 | 500 | 99.45 | 99.77 | 99.88 | 99.83 | 100.00 | 97.35 | 96.50 | 0.56 | 7.26 |
| 35 | 354 | 98.77 | 99.44 | 99.89 | 99.58 | 99.98 | 97.35 | 96.50 | 0.43 | 4.61 |
| 48 | 250 | 97.20 | 98.47 | 99.49 | 99.84 | 99.91 | 97.35 | 96.50 | 0.33 | 3.74 |
| 65 | 177 | 92.86 | 94.94 | 97.51 | 98.28 | 99.65 | 97.29 | 96.41 | 0.25 | 1.65 |
| 100 | 125 | 83.53 | 83.81 | 89.59 | 87.93 | 98.83 | 94.36 | 95.19 | 0.19 | 0.99 |
| 150 | 88 | 72.40 | 61.68 | 70.83 | 71.26 | 96.61 | 90.72 | 87.75 | 0.15 | 0.59 |
| 200 | 63 | 61.28 | 33.40 | 43.85 | 48.63 | 88.96 | 75.18 | 67.23 | 0.11 | 0.35 |
| 270 | 44 | 50.19 | 16.00 | 24.90 | 31.84 | 73.76 | 51.42 | 35.86 | 0.08 | 0.21 |
| 400 | 31 | 39.37 | 9.16 | 15.48 | 22.18 | 54.65 | 38.29 | 18.53 | 0.05 | 0.13 |
| 500 | 22 | 31.72 | 6.22 | 10.99 | 16.52 | 44.15 | 31.48 | 9.53 | 0.04 | 0.08 |
| 1 | 16 | 23.69 | 4.22 | 7.58 | 12.00 | 32.59 | 27.95 | 4.88 | 0.03 | 0.05 |
| 2 | 11 | 17.69 | 2.96 | 5.36 | 8.74 | 24.03 | 25.56 | 1.58 | 0.02 | 0.03 |
| 3 | 8 | 13.21 | 2.14 | 3.85 | 6.31 | 17.71 | 24.27 | 0.01 | 0.01 | 0.02 |
| 4 | 5 | 9.86 | 1.58 | 2.79 | 4.73 | 13.06 | 24.26 | 0.00 | 0.00 | 0.00 |

c) Circuit Feed Rate: 69.90 t/h

Rod Mill Data / Model # 1

VARIABLES DE SORTIE

DEBIT= 69.90 CONSTANTE= 1448.00 SCALPAGE= 22.00

| MESH | X | ALIM | DECH | R | S |
|---|---|---|---|---|---|
| 38100 | 38100 | 100.00 | 100.00 | 1.00000 | 1.00000 |
| 26670 | 26670 | 97.40 | 100.00 | 0.53400 | 0.81200 |
| 18796 | 18796 | 81.30 | 100.00 | 0.50900 | 0.70700 |
| 13208 | 13208 | 58.40 | 100.00 | 0.46900 | 0.55900 |
| 9398 | 9398 | 44.60 | 100.00 | 0.32900 | 0.42300 |
| 6604 | 6604 | 35.40 | 100.00 | 0.26400 | 0.32700 |
| 4699 | 4699 | 28.70 | 100.00 | 0.21300 | 0.27200 |
| 3327 | 3327 | 25.10 | 100.00 | 0.17000 | 0.24400 |
| 2362 | 2362 | 22.20 | 99.86 | 0.13700 | 0.11900 |
| 1651 | 1651 | 19.30 | 97.35 | 0.11000 | 0.01960 |
| 1168 | 1168 | 17.00 | 92.41 | 0.08900 | 0.15700 |
| 833 | 833 | 15.00 | 84.00 | 0.07100 | 0.38160 |
| 589 | 589 | 14.50 | 74.26 | 0.05400 | 0.00219 |
| 417 | 417 | 12.30 | 64.96 | 0.04540 | 0.00024 |
| 295 | 295 | 11.30 | 56.23 | 0.03620 | 0.00041 |
| 210 | 210 | 10.40 | 48.92 | 0.02910 | 0.00012 |
| 147 | 147 | 9.50 | 42.71 | 0.02350 | 0.00068 |
| 105 | 105 | 8.70 | 37.44 | 0.01870 | 0.00000 |
| 74 | 74 | 8.00 | 32.86 | 0.01520 | 0.00000 |
| 53 | 53 | 7.00 | 27.64 | 0.01210 | 0.00000 |
| 37 | 37 | 5.00 | 21.40 | 0.00940 | 0.20500 |
| 25 | 25 | 4.60 | 17.85 | 0.00000 | 0.00000 |

RESULTATS

CIRCUIT PRIMAIRE.

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCE1]= | 0.000 | HCE5]= | 0.330 | HCE9] = | 0.950 | HCE13]= | 1.478 | RO = | 4.50 |
| HCE2]= | 0.010 | HCE6]= | 0.047 | HCE10]= | 5.396 | HCE14]= | 2.889 | QE = | 17.44 |
| HCE3]= | 0.001 | HCE7]= | 0.000 | HCE11]= | 2.589 | HCE15]= | 0.024 | DE1= | 6.40 |
| HCE4]= | 1.258 | HCE8]= | 10.710 | HCE12]= | 1.402 | HCE16]= | 0.030 | DE2= | 17.60 |

PST= 0.100
MLP= 2.600
NC = 1.000

VARIABLES DE SORTIE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CIR= 1.772 | DESU= 41.440 | DENS =77.02 | D150= 69.16 |
| DS =193.751 | RF = 16.356 | DENSO=88.34 | U50 =133.17 |
| RS =123.860 | QE = 57.796 | DENSU=62.78 | TAU = 0.81 |
| QST= 69.892 | QEB = 33.956 | DENSB=78.48 | |
| W = 1.000 | QV =100.852 | | |
| | RF = 28.299 | | |

| MESH | X | ALIM | ALBP | DECBR | ALCYC | SUPU | C | CC | B | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 2830 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 28.31 |
| 8 | 2000 | 99.46 | 99.70 | 100.00 | 99.81 | 100.00 | 100.00 | 100.00 | 0.81 | 17.84 |
| 10 | 1410 | 97.35 | 98.49 | 99.98 | 99.03 | 100.00 | 99.74 | 99.63 | 0.65 | 11.25 |
| 14 | 1000 | 92.41 | 95.58 | 99.86 | 97.17 | 99.99 | 99.00 | 98.60 | 0.52 | 7.09 |
| 20 | 707 | 84.00 | 90.27 | 99.24 | 93.74 | 99.89 | 98.25 | 97.56 | 0.42 | 4.47 |
| 28 | 500 | 74.26 | 83.06 | 97.40 | 89.05 | 99.66 | 97.48 | 96.49 | 0.33 | 2.81 |
| 35 | 354 | 64.94 | 73.92 | 93.29 | 83.06 | 99.25 | 95.90 | 94.28 | 0.27 | 1.77 |
| 48 | 250 | 56.23 | 61.63 | 85.38 | 74.86 | 98.31 | 92.68 | 89.80 | 0.21 | 1.12 |
| 65 | 177 | 48.92 | 46.04 | 72.68 | 64.11 | 96.13 | 81.67 | 74.44 | 0.17 | 0.70 |
| 100 | 125 | 42.71 | 30.74 | 57.45 | 52.13 | 90.05 | 59.79 | 43.99 | 0.14 | 0.44 |
| 150 | 83 | 37.44 | 22.00 | 45.80 | 42.78 | 79.62 | 43.42 | 21.09 | 0.11 | 0.28 |
| 200 | 63 | 32.86 | 17.18 | 37.99 | 35.69 | 68.50 | 35.93 | 10.64 | 0.09 | 0.18 |
| 270 | 44 | 27.64 | 13.59 | 30.24 | 29.30 | 57.15 | 31.94 | 5.02 | 0.07 | 0.11 |
| 400 | 31 | 21.40 | 10.30 | 23.46 | 22.72 | 44.73 | 29.91 | 2.25 | 0.05 | 0.07 |
| 500 | 22 | 17.85 | 8.22 | 18.52 | 18.28 | 36.10 | 28.75 | 0.63 | 0.00 | 0.00 |



Model # 1

RESULTATS

CIRCUIT SECONDAIRE.

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCF11= | 0.000 | HCF51= | 0,230 | HCF91 = | 0,965 | HCF131= | 1,404 | RO = | 4,50 |
| HCF21= | 0,003 | HCF61= | 0,024 | HCF101= | 5,374 | HCF141= | 2,238 | DF = | 41,44 |
| HCF31= | 0,000 | HCF71= | 0,000 | HCF111= | 2,738 | HCF151= | 0,000 | DF1= | 102,50 |
| HCF41= | 1,532 | HCF81= | 4,450 | HCF121= | 1,778 | HCF161= | 0,000 | DF2= | 10,40 |
| | | | | | | | | PST= | 0,100 |
| | | | | | | | | RUF= | 2,600 |
| | | | | | | | | NC = | 3,000 |

VARIABLES DE SORTIE

| | | | | |
|---|---|---|---|---|
| CIR= 2,002 | DESU=154,340 | DENS =51,58 | D150=124,79 | |
| DS =209,849 | RE = 42,637 | DENSO=76,65 | D50 = 49,99 | |
| RS =139,959 | DF =196,977 | DENSU=31,17 | TAU = 0,43 | |
| DST= 69,890 | DER = 53,037 | DENSR=72,52 | | |
| W = 1,000 | DU =243,610 | | | |
| | RF = 21,646 | | | |

| MESH | X | ALTM | ALBR | DECBR | ALCYC | SURU | C | CC | R | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 707 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 1,00 | 12,88 |
| 28 | 500 | 99,66 | 99,83 | 99,99 | 99,88 | 100,00 | 100,00 | 100,00 | 0,56 | 7,26 |
| 35 | 354 | 99,25 | 99,58 | 99,94 | 99,79 | 100,00 | 97,26 | 96,50 | 0,43 | 4,61 |
| 48 | 250 | 98,31 | 98,95 | 99,78 | 99,29 | 99,96 | 97,24 | 96,50 | 0,33 | 2,76 |
| 65 | 177 | 96,13 | 97,08 | 98,94 | 98,01 | 99,86 | 97,21 | 96,44 | 0,25 | 1,65 |
| 100 | 125 | 90,05 | 90,10 | 94,80 | 93,21 | 99,46 | 96,51 | 95,54 | 0,19 | 0,99 |
| 150 | 88 | 79,62 | 71,93 | 81,18 | 80,66 | 98,14 | 91,71 | 89,43 | 0,15 | 0,59 |
| 200 | 63 | 68,50 | 44,10 | 56,38 | 60,42 | 93,13 | 77,29 | 71,02 | 0,11 | 0,35 |
| 270 | 44 | 57,15 | 22,02 | 33,49 | 41,37 | 80,12 | 52,37 | 39,21 | 0,08 | 0,21 |
| 400 | 31 | 44,73 | 12,12 | 20,79 | 28,76 | 62,09 | 37,51 | 20,25 | 0,06 | 0,13 |
| 500 | 22 | 36,10 | 8,10 | 14,37 | 21,61 | 48,67 | 29,83 | 10,45 | 0,04 | 0,08 |
| 1 | 16 | 26,96 | 5,41 | 9,93 | 15,60 | 36,01 | 25,89 | 5,42 | 0,03 | 0,05 |
| 2 | 11 | 20,13 | 3,77 | 7,00 | 11,37 | 26,60 | 23,20 | 1,99 | 0,02 | 0,03 |
| 3 | 8 | 15,03 | 2,72 | 5,01 | 8,35 | 19,63 | 21,81 | 0,21 | 0,01 | 0,02 |
| 4 | 5 | 11,22 | 2,00 | 3,63 | 6,16 | 14,49 | 21,65 | 0,00 | 0,00 | 0,00 |



Model # 1

d) Circuit Feed Rate: 61.96 t/h

Rod Mill Data / Model # 1

VARIABLES DE SORTIE

DEBIT= 61.96 CONSTANTE= 1448.00 ECALAGE= 22.00

| MESH | X | ALIM | DEFR | R | S |
|---|---|---|---|---|---|
| 38100 | 38100 | 100.00 | 100.00 | 1.00000 | 1.00000 |
| 26670 | 26670 | 97.70 | 100.00 | 0.63400 | 0.81700 |
| 18796 | 18796 | 89.50 | 100.00 | 0.50900 | 0.70700 |
| 13208 | 13208 | 71.90 | 100.00 | 0.40900 | 0.55900 |
| 9398 | 9398 | 60.70 | 100.00 | 0.33800 | 0.47300 |
| 6604 | 6604 | 50.80 | 100.00 | 0.26400 | 0.37700 |
| 4 | 4699 | 42.90 | 100.00 | 0.21300 | 0.13770 |
| 6 | 3327 | 37.50 | 100.00 | 0.17600 | 0.03890 |
| 9 | 2362 | 32.50 | 100.00 | 0.13700 | 0.11900 |
| 10 | 1651 | 27.70 | 99.23 | 0.11000 | 0.01940 |
| 14 | 1168 | 23.90 | 96.57 | 0.08990 | 0.19700 |
| 20 | 833 | 20.80 | 90.63 | 0.07100 | 0.34100 |
| 28 | 589 | 18.60 | 81.60 | 0.05480 | 0.00219 |
| 35 | 417 | 16.90 | 72.62 | 0.04560 | 0.00024 |
| 48 | 295 | 15.60 | 63.65 | 0.03660 | 0.00041 |
| 65 | 210 | 14.40 | 55.67 | 0.02910 | 0.00012 |
| 100 | 147 | 13.20 | 48.96 | 0.02350 | 0.00048 |
| 150 | 105 | 12.10 | 43.03 | 0.01870 | 0.00000 |
| 200 | 74 | 11.00 | 38.10 | 0.01520 | 0.00000 |
| 270 | 53 | 9.80 | 33.22 | 0.01210 | 0.00000 |
| 400 | 37 | 7.00 | 25.91 | 0.00940 | 0.20500 |
| 500 | 25 | 4.20 | 21.47 | 0.00000 | 0.00000 |

RESULTATS

CIRCUIT PRIMAIRE.

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCF1]= | 0.000 | HCF5]= | 0.330 | HCF9] = | 0.950 | HCF13]= | 1.429 | MI = | 4.50 |
| HCF2]= | 0.010 | HCF6]= | 0.047 | HCF10]= | 5.396 | HCF14]= | 2.989 | DR = | 17.70 |
| HCF3]= | 0.001 | HCF7]= | 0.000 | HCF11]= | 2.589 | HCF15]= | 0.024 | DE1= | 5.00 |
| HCF4]= | 1.258 | HCF8]= | 10.710 | HCF12]= | 1.402 | HCF16]= | 0.030 | DE2= | 12.50 |
| | | | | | | | | PST= | 0.106 |
| | | | | | | | | MLP= | 2.400 |
| | | | | | | | | DF = | 1.000 |

VARIABLES DE SORTIE

| | | | |
|---|---|---|---|
| CIR= 1.420 | DESU= 39.890 | DENS =74.48 | D150= 62.59 |
| DS =149.934 | RE = 11.477 | DENSU=83.46 | D50 =116.47 |
| RS = 87.982 | DE = 51.367 | DENSU=40.83 | TAU = 1.25 |
| OST= 61.952 | DFR = 28.977 | DENSR=75.22 | |
| W = 1.000 | DO = 84.686 | | |
| | RF = 22.343 | | |

| MESH | X | ALIM | ALBR | DECBR | ALCYC | SURV | C | CC | F | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 2830 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 31.25 |
| 8 | 2000 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.81 | 19.70 |
| 10 | 1410 | 99.23 | 99.45 | 100.00 | 99.69 | 100.00 | 100.00 | 100.00 | 0.65 | 12.41 |
| 14 | 1000 | 96.57 | 97.56 | 99.97 | 98.57 | 100.00 | 99.23 | 99.00 | 0.52 | 7.82 |
| 20 | 707 | 90.63 | 93.20 | 99.77 | 95.99 | 99.95 | 98.42 | 97.96 | 0.42 | 4.93 |
| 28 | 500 | 81.60 | 86.08 | 98.89 | 91.74 | 99.79 | 97.61 | 96.92 | 0.33 | 3.11 |
| 35 | 354 | 72.62 | 77.61 | 96.54 | 86.65 | 99.49 | 96.61 | 95.63 | 0.27 | 1.96 |
| 48 | 250 | 63.65 | 66.46 | 91.31 | 79.88 | 98.94 | 94.08 | 92.38 | 0.21 | 1.23 |
| 65 | 177 | 55.67 | 52.17 | 81.74 | 70.97 | 97.66 | 86.16 | 82.17 | 0.17 | 0.78 |
| 100 | 125 | 48.96 | 36.13 | 67.86 | 60.04 | 94.00 | 66.62 | 57.02 | 0.14 | 0.49 |
| 150 | 88 | 43.03 | 24.28 | 54.24 | 49.60 | 85.57 | 44.01 | 27.90 | 0.11 | 0.31 |
| 200 | 63 | 38.10 | 18.38 | 44.31 | 41.74 | 74.92 | 33.19 | 13.92 | 0.09 | 0.19 |
| 270 | 44 | 33.22 | 14.58 | 36.29 | 35.02 | 64.05 | 27.57 | 6.73 | 0.07 | 0.12 |
| 400 | 31 | 25.91 | 10.96 | 28.29 | 27.31 | 50.53 | 24.79 | 3.15 | 0.05 | 0.08 |
| 500 | 22 | 21.47 | 8.71 | 22.35 | 21.99 | 40.84 | 23.24 | 1.16 | 0.00 | 0.00 |

Model # 1

RESULTATS

CIRCUIT SECONDAIRE

VARIABLES D'ENTREE

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| HCE11= | 0.000 | HCE51= | 0.230 | HCE91= | 0.965 | HCE131= | 1.406 | NO = 4.50 |
| HCE21= | 0.003 | HCE61= | 0.025 | HCE101= | 5.321 | HCE141= | 2.238 | DF = 29.89 |
| HCE31= | 0.000 | HCE71= | 0.000 | HCE111= | 2.238 | HCE151= | 0.000 | DE1= 74.50 |
| HCE41= | 1.532 | HCE81= | 4.430 | HCE121= | 1.728 | HCE161= | 0.000 | DF = 3.95 |

VARIABLES DE SORTIE

| | | | | |
|---|---|---|---|---|
| CIR= 1.401 | DESU=119.640 | DENS =50.35 | DI50=105.97 | |
| DS =148.762 | RF = 27.033 | DENSU=76.25 | D50 = 49.54 | |
| RS = 84.811 | DE =146.673 | DENSH=34.12 | TAU = 0.69 | |
| QST= 61.951 | DEB = 30.283 | DENSB=74.14 | | |
| W = 1.000 | DU =179.731 | | | |
| | RF = 18.431 | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| MESH | X | AI TM | AI BR | DECBR | ALCYC | SHRU | C | CC | R | S |
| 20 | 707 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 12.88 |
| 28 | 500 | 99.79 | 99.85 | 100.00 | 99.91 | 100.00 | 100.00 | 100.00 | 0.56 | 7.70 |
| 35 | 354 | 99.49 | 99.62 | 99.98 | 99.78 | 100.00 | 97.15 | 96.50 | 0.43 | 4.61 |
| 48 | 250 | 98.94 | 99.17 | 99.91 | 99.51 | 99.98 | 97.14 | 96.50 | 0.33 | 2.76 |
| 65 | 177 | 97.66 | 97.97 | 99.54 | 98.76 | 99.93 | 97.10 | 96.45 | 0.25 | 1.65 |
| 100 | 125 | 94.00 | 93.46 | 97.55 | 94.07 | 99.74 | 96.41 | 95.60 | 0.19 | 0.99 |
| 150 | 88 | 85.57 | 79.29 | 88.88 | 87.50 | 99.00 | 91.62 | 89.72 | 0.15 | 0.59 |
| 200 | 63 | 74.92 | 53.76 | 68.61 | 71.28 | 95.73 | 76.94 | 71.73 | 0.11 | 0.35 |
| 270 | 44 | 64.05 | 29.53 | 44.88 | 52.84 | 85.54 | 50.98 | 39.90 | 0.08 | 0.21 |
| 400 | 31 | 50.53 | 16.26 | 28.49 | 37.67 | 67.67 | 35.24 | 20.60 | 0.06 | 0.13 |
| 500 | 22 | 40.84 | 10.73 | 19.79 | 28.59 | 53.44 | 27.11 | 10.63 | 0.04 | 0.08 |
| 1 | 16 | 30.50 | 7.08 | 13.61 | 20.65 | 39.66 | 22.94 | 5.53 | 0.03 | 0.05 |
| 2 | 11 | 22.77 | 4.89 | 9.58 | 15.07 | 29.35 | 20.10 | 2.05 | 0.02 | 0.03 |
| 3 | 8 | 17.00 | 3.51 | 6.86 | 11.08 | 21.70 | 18.64 | 0.26 | 0.01 | 0.02 |
| 4 | 5 | 12.70 | 2.59 | 4.97 | 8.19 | 16.03 | 18.43 | 0.00 | 0.00 | 0.00 |



Model # 1

## 2. SIMULATION RESULTS USING ROD MILL MODEL # 2 (with classifier model # 1)

### a) Circuit Feed Rate: 87:11 t/h Rod Mill Data / Model # 2

---

VARIABLE DT SORTIF

DENSITY= 87.11 CONSTANT= 1250.00 SCALE= 22.00

| MESH | X | ALF | DFOR | 'P' | I |
|---|---|---|---|---|---|
| 38100 | 38100 | 100.00 | 100.00 | 1.00000 | 0.00000 |
| 24670 | 24670 | 97.20 | 100.00 | 0.95700 | 0.35611 |
| 19796 | 19796 | 84.00 | 100.00 | 0.82700 | 0.72854 |
| 13208 | 13208 | 63.80 | 100.00 | 0.62900 | 0.93304 |
| 9398 | 9398 | 52.40 | 100.00 | 0.51600 | 0.99704 |
| 6604 | 6604 | 41.80 | 100.00 | 0.41210 | 0.95795 |
| 4699 | 4699 | 34.00 | 100.00 | 0.33470 | 0.80136 |
| 3327 | 3327 | 28.30 | 100.00 | 0.27880 | 0.62547 |
| 2362 | 2362 | 25.20 | 95.37 | 0.24800 | 0.48583 |
| 1671 | 1671 | 21.30 | 89.98 | 0.20980 | 0.32817 |
| 1168 | 1168 | 18.40 | 83.52 | 0.18130 | 0.20567 |
| 833 | 833 | 16.30 | 78.20 | 0.16050 | 0.13424 |
| 589 | 589 | 14.30 | 66.19 | 0.14090 | 0.08449 |
| 417 | 417 | 13.10 | 57.67 | 0.12900 | 0.05142 |
| 295 | 295 | 11.90 | 49.56 | 0.11710 | 0.03257 |
| 210 | 210 | 10.90 | 42.15 | 0.10730 | 0.02091 |
| 137 | 137 | 9.80 | 35.43 | 0.09650 | 0.01244 |
| 105 | 105 | 9.00 | 30.59 | 0.08860 | 0.00741 |
| 74 | 74 | 8.10 | 24.70 | 0.07970 | 0.00458 |
| 53 | 53 | 6.90 | 20.14 | 0.06790 | 0.00253 |
| 37 | 37 | 4.80 | 15.69 | 0.04720 | 0.00113 |
| 25 | 25 | 4.50 | 12.76 | 0.04430 | 0.00000 |

RESULTATS

CIRCUIT PRIMAIRE

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCT1= | 9.000 | HCT5= | 0.330 | HCL9= | 0.950 | HCT13= | 1.475 | KH = | 1.50 |
| HCT2= | 6.010 | HCT6= | 0.042 | HCL10= | 5.396 | HCT14= | 2.582 | GR = | 15.00 |
| HCT3= | 6.001 | HCT7= | 0.000 | HCT11= | 2.589 | HCL15= | 0.024 | DEL= | 8.50 |
| HCT4= | 1.258 | HCT8= | 10.210 | HCL12= | 1.305 | HCL16= | 0.030 | HE2= | 16.40 |
| | | | | | | | | PCT= | 0.100 |
| | | | | | | | | BLP= | 2.406 |
| | | | | | | | | PT = | 1.000 |

VARIABLES DE SORTIE

| | | | |
|---|---|---|---|
| CTR= 3.139 | DESU= 44.230 | DEBU =204.94 | DIS= 85.00 |
| DS =360.544 | DE = 40.484 | DEMSU=27.85 | DSA =200.33 |
| RS =273.444 | DE = 84.916 | DEMSU=44.20 | CAP = 0.20 |
| DST= 87.100 | DEB = 57.086 | DEISR=82.77 | |
| W = 1.000 | DV =165.037 | | |
| | RF = 47.913 | | |

| MESH | X | ALIM | ALBR | DEBR | ALCYC | SHELL | I | PC | B | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 2830 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 17.00 |
| 8 | 2000 | 95.37 | 98.40 | 99.87 | 98.79 | 100.00 | 99.99 | 99.45 | 0.81 | 10.71 |
| 10 | 1416 | 89.98 | 96.25 | 99.44 | 97.15 | 99.93 | 99.17 | 98.41 | 0.65 | 6.73 |
| 14 | 1000 | 82.92 | 93.25 | 98.16 | 94.38 | 99.89 | 98.63 | 97.38 | 0.52 | 3.75 |
| 20 | 707 | 74.78 | 87.99 | 95.13 | 90.23 | 99.65 | 98.05 | 96.97 | 0.42 | 2.68 |
| 28 | 500 | 66.19 | 78.55 | 89.08 | 83.52 | 99.11 | 96.83 | 93.91 | 0.33 | 1.69 |
| 35 | 354 | 57.67 | 65.41 | 78.18 | 73.22 | 97.76 | 93.80 | 88.10 | 0.27 | 1.06 |
| 48 | 250 | 49.56 | 47.76 | 61.95 | 58.95 | 94.10 | 84.32 | 69.90 | 0.21 | 0.69 |
| 65 | 177 | 42.13 | 32.46 | 46.17 | 45.20 | 85.17 | 68.07 | 38.69 | 0.17 | 0.42 |
| 100 | 125 | 35.43 | 24.07 | 35.97 | 35.81 | 72.80 | 57.66 | 18.70 | 0.14 | 0.27 |
| 150 | 88 | 29.59 | 18.85 | 28.79 | 28.98 | 60.78 | 52.68 | 9.15 | 0.11 | 0.17 |
| 200 | 63 | 24.60 | 15.10 | 23.95 | 23.58 | 50.19 | 50.29 | 4.56 | 0.09 | 0.11 |
| 270 | 44 | 20.14 | 12.12 | 19.25 | 19.08 | 40.95 | 48.90 | 1.89 | 0.07 | 0.07 |
| 400 | 31 | 15.69 | 9.47 | 14.54 | 14.82 | 31.92 | 48.13 | 0.41 | 0.05 | 0.04 |
| 500 | 22 | 12.76 | 7.43 | 11.45 | 11.76 | 25.36 | 47.91 | 0.00 | 0.00 | 0.00 |

Model # II

RESULTATS

CIRCUIT SECONDAIRE.

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCE11= | 0.000 | HCF51= | 0.230 | HCF91 = | 0.965 | HCF131= | 1.304 | ED = | 5.50 |
| HCE21= | 0.003 | HCF61= | 0.024 | HCF101= | 5.343 | HCF141= | 2.938 | DF = | 44.25 |
| HCE31= | 0.000 | HCF71= | 0.000 | HCF111= | 2.738 | HCF151= | 0.000 | DF1= | 135.20 |
| HCE41= | 1.532 | HCF81= | 1.430 | HCF121= | 1.278 | HCF161= | 0.000 | DF2= | 13.80 |
| | | | | | | | | PS1= | 0.100 |
| | | | | | | | | ALP= | 2.000 |
| | | | | | | | | NC = | 3.000 |

VARIABLES DE SORTIE

| | | | |
|---|---|---|---|
| CIR= 4.025 | DESU=194.230 | DEMS =61.3° | DI50=148.97 |
| DS =437.699 | RF = 25.315 | DEMS1=82.32 | D50 = 53.98 |
| RS =350.599 | DE =269.565 | DEMSU=30.94 | TAU = 0.17 |
| DST= 87.100 | DER = 89.115 | DEDSR=79.7% | |
| W = 1.000 | DU =366.812 | | |
| | RF = 27.942 | | |

| MESH | X | ALTN | ALBR | DECBR | ALCYC | SURV | C | CI | R | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 707 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 12.80 |
| 28 | 500 | 99.11 | 99.73 | 99.95 | 99.29 | 100.00 | 97.48 | 96.50 | 0.54 | 7.26 |
| 35 | 354 | 97.76 | 99.18 | 99.73 | 99.33 | 99.94 | 97.48 | 96.50 | 0.43 | 4.51 |
| 48 | 250 | 94.10 | 97.23 | 98.63 | 97.73 | 99.24 | 97.48 | 96.50 | 0.33 | 3.24 |
| 65 | 177 | 85.17 | 90.35 | 93.29 | 92.63 | 99.09 | 97.40 | 96.39 | 0.25 | 1.65 |
| 100 | 125 | 72.80 | 74.44 | 80.53 | 78.99 | 97.31 | 96.34 | 94.92 | 0.19 | 0.99 |
| 150 | 88 | 60.78 | 48.00 | 54.07 | 52.01 | 93.26 | 90.30 | 86.54 | 0.15 | 0.59 |
| 200 | 63 | 50.19 | 22.10 | 30.61 | 38.03 | 82.07 | 74.55 | 64.68 | 0.11 | 0.35 |
| 270 | 44 | 40.95 | 10.58 | 16.85 | 21.45 | 66.22 | 52.35 | 33.87 | 0.08 | 0.21 |
| 400 | 31 | 31.92 | 6.19 | 10.22 | 14.94 | 50.15 | 40.56 | 17.51 | 0.06 | 0.13 |
| 500 | 22 | 25.36 | 4.20 | 7.43 | 11.06 | 38.40 | 34.41 | 8.94 | 0.04 | 0.08 |
| 1 | 16 | 18.94 | 2.87 | 5.38 | 7.92 | 28.23 | 31.32 | 4.55 | 0.03 | 0.05 |
| 2 | 11 | 14.14 | 2.03 | 3.67 | 5.25 | 20.74 | 29.01 | 1.49 | 0.02 | 0.03 |
| 3 | 8 | 10.56 | 1.47 | 2.65 | 4.21 | 15.24 | 27.94 | 0.00 | 0.01 | 0.02 |
| 4 | 5 | 7.88 | 1.08 | 1.90 | 3.06 | 11.20 | 27.94 | 0.00 | 0.00 | 0.00 |



Model # II

b) Circuit Feed Rate: 79.40 t/h

Rod Mill Data / Model # 2

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[illegible]

[illegible] = 79.40 [illegible] = 1290.00 [illegible] = 22.00

| MESH | X | W | dW/dY | R | Y |
|---|---|---|---|---|---|
| 28100 | 39100 | 100.00 | 100.00 | 1.00000 | 1.00000 |
| 26670 | 26670 | 97.50 | 100.00 | 0.97500 | 0.95111 |
| 18706 | 18706 | 91.50 | 160.00 | 0.93700 | 0.89363 |
| 13200 | 13200 | 87.10 | 300.00 | 0.92000 | 0.82434 |
| 9398 | 9398 | 86.00 | 100.00 | 0.98600 | 0.83304 |
| 6604 | 6604 | 77.00 | 100.00 | 0.78100 | 0.65306 |
| 4 | 4699 | 70.60 | 100.00 | 0.91700 | 0.47704 |
| 3 | 3327 | 64.10 | 90.13 | 0.91700 | 0.39178 |
| 2 | 2363 | 59.90 | 96.50 | 0.93500 | 0.33522 |
| 10 | 1651 | 57.60 | 91.00 | 0.96200 | 0.28528 |
| 14 | 1169 | 17.10 | 85.50 | 0.94600 | 0.24617 |
| 20 | 833 | 13.90 | 77.80 | 0.93800 | 0.20947 |
| 28 | 589 | 15.40 | 69.40 | 0.92000 | 0.17934 |
| 35 | 417 | 12.10 | 60.85 | 0.91400 | 0.15540 |
| 48 | 295 | 11.10 | 52.55 | 0.91000 | 0.13132 |
| 65 | 210 | 10.20 | 44.82 | 0.90700 | 0.11347 |
| 100 | 147 | 9.30 | 37.82 | 0.90500 | 0.09594 |
| 150 | 105 | 8.50 | 31.65 | 0.90300 | 0.08044 |
| 200 | 74 | 7.70 | 26.29 | 0.90200 | 0.07041 |
| 270 | 53 | 6.90 | 21.69 | 0.90100 | 0.06058 |
| 400 | 37 | 5.10 | 17.20 | 0.90100 | 0.05152 |
| 500 | 25 | 4.60 | 13.93 | 0.90000 | 0.04318 |

RESULTATS

CIRCUIT PRIMAIRE

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCF1= | 0.000 | HCF5= | 0.330 | HCF9= | 0.956 | HCF13= | 1.478 | EO = | 3.50 |
| HCF2= | 0.010 | HCF6= | 0.047 | HCF10= | 5.396 | HCF14= | 2.809 | QS = | 19.05 |
| HCF3= | 0.001 | HCF7= | 0.000 | HCF11= | 2.589 | HCF15= | -0.033 | DEL= | 6.80 |
| HCF4= | 1.258 | HCF8= | -10.710 | HCF12= | 1.402 | HCF16= | 0.030 | DF2= | 17.00 |
| | | | | | | | | PSI= | 0.100 |
| | | | | | | | | PHP= | 2.400 |
| | | | | | | | | DC = | 1.000 |

VARIABLES DE SORTIE

| | | | |
|---|---|---|---|
| CTR= 2.329 | DFSH= 42.250 | DFMS =79.54 | D150= 74.71 |
| DS =264.297 | DE = 25.240 | DFDSH=67.29 | D50 =160.63 |
| RS =184.906 | DF = 67.990 | DFPSH=45.00 | TAH = 0.44 |
| QST= 79.391 | DFB = 42.230 | DFMSH=81.40 | |
| W = 1.000 | QV =126.735 | | |
| | PF = 37.125 | | |

| MESH | X | ALIM | ALBP | REFUS. | ALFAC | SURD | C | PC | R | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 9830 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 1,00 | 22,31 |
| 8 | 2000 | 96,50 | 98,47 | 99,97 | 98,93 | 100,00 | 100,00 | 100,00 | 0,81 | 18,09 |
| 10 | 1410 | 91,89 | 94,36 | 99,84 | 97,45 | 100,00 | 99,41 | 99,67 | 0,65 | 9,24 |
| 14 | 1000 | 85,50 | 93,14 | 99,35 | 95,19 | 99,96 | 98,77 | 98,83 | 0,52 | 5,80 |
| 20 | 707 | 77,82 | 88,47 | 97,93 | 91,88 | 99,82 | 98,11 | 96,99 | 0,42 | 3,68 |
| 28 | 500 | 69,42 | 81,67 | 94,60 | 87,03 | 99,50 | 97,33 | 95,71 | 0,33 | 2,32 |
| 35 | 354 | 60,85 | 71,60 | 87,93 | 79,79 | 98,87 | 95,43 | 93,73 | 0,27 | 1,46 |
| 48 | 250 | 52,55 | 57,04 | 76,23 | 69,12 | 97,25 | 89,50 | 83,30 | 0,21 | 0,92 |
| 65 | 177 | 44,82 | 39,54 | 59,99 | 55,43 | 92,46 | 74,52 | 59,48 | 0,17 | 0,58 |
| 100 | 125 | 37,82 | 26,66 | 45,73 | 43,35 | 82,21 | 55,78 | 29,68 | 0,14 | 0,37 |
| 150 | 88 | 31,65 | 19,88 | 36,21 | 34,84 | 69,69 | 45,14 | 14,34 | 0,11 | 0,23 |
| 200 | 63 | 26,29 | 15,54 | 29,12 | 28,97 | 57,90 | 41,69 | 7,27 | 0,09 | 0,15 |
| 270 | 44 | 21,69 | 12,38 | 23,49 | 22,95 | 47,58 | 39,23 | 3,35 | 0,07 | 0,09 |
| 400 | 31 | 17,20 | 9,58 | 18,29 | 17,96 | 37,49 | 37,92 | 1,27 | 0,05 | 0,06 |
| 500 | 22 | 13,93 | 7,54 | 14,33 | 14,21 | 29,73 | 37,15 | 0,03 | 0,00 | 0,00 |

Model # II

MESH 1675

CIRCUIT SECONDAIRE.

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCF1]= | 0.000 | HCF5]= | 0.230 | HCF9]= | 0.965 | HCF13]= | 1.305 | MT = | 4.50 |
| HCF2]= | 0.003 | HCF6]= | 0.026 | HCF10]= | 5.374 | HCF14]= | 2.238 | DF = | 42.75 |
| HCF3]= | 0.000 | HCF7]= | 0.000 | HCF11]= | 2.238 | HCF15]= | 0.000 | DF1= | 166.77 |
| HCF4]= | 1.532 | HCF8]= | 4.430 | HCF12]= | 1.778 | HCF16]= | 0.000 | DF2= | 10.05 |
| | | | | | | | | ESF= | 0.100 |
| | | | | | | | | MLP= | 2.000 |
| | | | | | | | | NP = | 2.000 |

VARIABLES DE SORTIE

| | | | | |
|---|---|---|---|---|
| CIR= 2.901 | DFSU=159.570 | DFDS =50.29 | DI50=138.55 | |
| DS =309.767 | PF = 53.112 | DFDSU=91.26 | D50 = 52.94 | |
| RS =230.376 | QF =212.489 | DFRSU=34.23 | TAU = 0.24 | |
| QST= 79.391 | DFP = 63.162 | DFRSR=78.48 | | |
| W = 1.000 | DU =281.519 | | | |
| | PF = 24.979 | | | |

| MESH | X | AI TM | AI BR | DFCBP | AI CYC | STRU | C | CC | R | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 707 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 12.88 |
| 28 | 500 | 99.52 | 99.82 | 99.98 | 99.86 | 100.00 | 97.37 | 96.50 | 0.56 | 7.20 |
| 35 | 354 | 98.87 | 99.52 | 99.90 | 99.63 | 99.98 | 97.37 | 96.50 | 0.43 | 5.61 |
| 48 | 250 | 97.25 | 98.57 | 99.49 | 98.91 | 99.90 | 97.37 | 96.50 | 0.33 | 3.76 |
| 65 | 177 | 93.46 | 94.85 | 97.31 | 96.07 | 99.61 | 97.30 | 96.40 | 0.25 | 1.65 |
| 100 | 125 | 82.21 | 80.96 | 88.63 | 86.98 | 98.45 | 96.32 | 95.10 | 0.19 | 0.99 |
| 150 | 88 | 69.69 | 58.92 | 67.99 | 68.62 | 95.99 | 90.50 | 82.34 | 0.15 | 0.59 |
| 200 | 63 | 57.90 | 30.69 | 40.10 | 44.74 | 87.21 | 74.75 | 66.38 | 0.11 | 0.45 |
| 270 | 44 | 47.58 | 14.45 | 22.83 | 29.12 | 71.88 | 51.34 | 35.14 | 0.08 | 0.31 |
| 400 | 31 | 37.49 | 8.40 | 14.51 | 20.40 | 55.22 | 38.60 | 18.16 | 0.06 | 0.14 |
| 500 | 22 | 29.73 | 5.43 | 10.02 | 15.08 | 42.47 | 31.98 | 9.33 | 0.04 | 0.08 |
| 1 | 16 | 22.20 | 3.83 | 6.97 | 10.87 | 31.31 | 28.55 | 4.74 | 0.03 | 0.05 |
| 2 | 11 | 16.58 | 2.69 | 4.93 | 7.91 | 23.06 | 26.18 | 1.61 | 0.02 | 0.04 |
| 3 | 8 | 12.38 | 1.95 | 3.54 | 5.80 | 16.98 | 24.97 | 0.00 | 0.01 | 0.02 |
| 4 | 5 | 9.24 | 1.43 | 2.56 | 4.27 | 12.51 | 24.97 | 0.00 | 0.00 | 0.00 |

Model # II

## c) Circuit Feed Rate: 69.90 t/h

### Rod Mill Data / Model # 2

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GARTNER OF NORTH

CFEED= 69.90 CUMSTOMIC= 1930.00 SCALPAC= 11.00

| MESH | X | ALM | DECB | R | S |
|---|---|---|---|---|---|
| 28100 | 28100 | 100.00 | 100.00 | 1.00000 | 1.00000 |
| 20470 | 20470 | 92.60 | 100.00 | 0.55700 | 0.35431 |
| 18794 | 18794 | 91.30 | 100.00 | 0.40700 | 0.23054 |
| 13202 | 13202 | 86.40 | 100.00 | 0.32700 | 0.16303 |
| 9398 | 9398 | 84.40 | 100.00 | 0.25840 | 0.12706 |
| 6604 | 6604 | 75.40 | 100.00 | 0.19310 | 0.09734 |
| 4 | 4699 | 28.70 | 100.00 | 0.13700 | 0.07144 |
| 6 | 3322 | 25.10 | 99.93 | 0.11290 | 0.05657 |
| 8 | 2342 | 22.20 | 98.64 | 0.07990 | 0.03538 |
| 10 | 1651 | 19.30 | 95.48 | 0.05640 | 0.02417 |
| 14 | 1168 | 17.00 | 90.25 | 0.04010 | 0.01624 |
| 20 | 833 | 15.00 | 83.39 | 0.02930 | 0.01134 |
| 28 | 589 | 13.50 | 75.41 | 0.02010 | 0.00789 |
| 35 | 417 | 12.30 | 64.88 | 0.01450 | 0.00519 |
| 48 | 295 | 11.30 | 54.23 | 0.01010 | 0.00367 |
| 65 | 210 | 10.40 | 50.18 | 0.00710 | 0.00258 |
| 100 | 147 | 9.50 | 47.57 | 0.00510 | 0.00184 |
| 150 | 105 | 8.70 | 35.79 | 0.00360 | 0.00121 |
| 200 | 74 | 8.00 | 29.85 | 0.00260 | 0.00088 |
| 270 | 54 | 7.00 | 21.63 | 0.00180 | 0.00059 |
| 400 | 37 | 5.00 | 19.53 | 0.00130 | 0.00039 |
| 500 | 25 | 4.40 | 15.93 | 0.00000 | 0.00000 |

RESULTATS

CIRCUIT PRIMAIRE.

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCE1]= | 0.000 | HCE5]= | 0.330 | HCE9] = | 0.950 | HCE13]= | 1.428 | RO = | 4.50 |
| HCE2]= | 0.010 | HCE6]= | 0.017 | HCE10]= | 5.396 | HCE14]= | [illegible] | [illegible] = | 17.44 |
| HCE3]= | 0.001 | HCE7]= | 0.000 | HCE11]= | 2.569 | HCE15]= | [illegible] | DE1= | [illegible] |
| HCE4]= | 1.258 | HCE8]= | 10.710 | HCE12]= | 1.402 | HCE16]= | 0.030 | DE2= | 17.60 |

VARIABLES DE SORTIE

| | | | | | |
|---|---|---|---|---|---|
| CIR= 1.001 | DESU= 41.440 | DENS =77.13 | D150= 66.27 | PST= 0.100 | |
| DS =195.811 | RE = 16.608 | DENSO=88.35 | D50 =134.09 | [illegible]= 2.600 | |
| RS =125.920 | DE = 58.048 | DENSU=62.78 | TAU = 0.79 | [illegible] = 1.600 | |
| QST= 69.891 | DEB = 34.208 | DENSB=78.64 | | | |
| W = 1.000 | DV =101.562 | | | | |
| | RF = 28.611 | | | | |

| MESH | X | ALIM | ALBR | DECBR | ALCYC | SURV | C | CC | B | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 2830 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 28.14 |
| 8 | 2000 | 98.64 | 99.25 | 100.00 | 99.51 | 100.00 | 100.00 | 100.00 | 0.81 | 17.74 |
| 10 | 1410 | 95.44 | 97.44 | 99.97 | 98.35 | 100.00 | 99.72 | 99.61 | 0.65 | 11.18 |
| 14 | 1000 | 90.25 | 94.42 | 99.82 | 96.40 | 99.98 | 98.99 | 98.58 | 0.52 | 7.04 |
| 20 | 707 | 83.39 | 90.07 | 99.24 | 93.58 | 99.90 | 98.25 | 97.54 | 0.42 | 4.44 |
| 28 | 500 | 75.41 | 84.08 | 97.57 | 89.66 | 99.71 | 97.47 | 96.46 | 0.33 | 2.80 |
| 35 | 354 | 66.88 | 75.69 | 93.69 | 84.12 | 99.32 | 95.89 | 94.24 | 0.27 | 1.76 |
| 48 | 250 | 58.33 | 63.77 | 86.01 | 76.13 | 98.40 | 92.59 | 89.62 | 0.21 | 1.11 |
| 65 | 177 | 50.14 | 47.49 | 72.98 | 64.82 | 96.05 | 81.42 | 73.97 | 0.17 | 0.70 |
| 100 | 125 | 42.57 | 31.10 | 57.04 | 51.87 | 89.31 | 59.52 | 43.30 | 0.14 | 0.44 |
| 150 | 88 | 35.79 | 21.61 | 44.87 | 41.63 | 77.49 | 43.45 | 20.79 | 0.11 | 0.28 |
| 200 | 63 | 29.86 | 16.35 | 36.05 | 33.84 | 65.36 | 36.10 | 10.49 | 0.09 | 0.18 |
| 270 | 44 | 24.63 | 12.79 | 29.09 | 27.49 | 54.99 | 32.19 | 5.01 | 0.07 | 0.11 |
| 400 | 31 | 19.54 | 9.82 | 22.69 | 21.52 | 42.73 | 30.19 | 2.21 | 0.05 | 0.07 |
| 500 | 22 | 15.83 | 7.72 | 17.78 | 17.08 | 33.96 | 29.04 | 0.60 | 0.00 | 0.00 |

Model # II

RESULTATS

CIRCUIT SECONDAIRE.

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCC1]= | 0.000 | HCC5]= | 0.230 | HCC9] = | 0.965 | HCC13]= | 1.406 | RO = | 4.50 |
| HCC2]= | 0.003 | HCC6]= | 0.076 | HCC10]= | 5.374 | HCC14]= | 2.238 | QE = | 41.44 |
| HCC3]= | 0.000 | HCC7]= | 0.000 | HCC11]= | 2.738 | HCC15]= | 0.000 | DE1= | 102.50 |
| HCC4]= | 1.532 | HCC8]= | 4.430 | HCC12]= | 1.778 | HCC16]= | 0.000 | DE2= | 10.40 |

VARIABLES DE SORTIE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CIR= | 2.193 | DESU= | 154.340 | DENS = | 52.95 | D150= | 126.43 |
| DS = | 223.193 | RE = | 43.952 | DENSO= | 77.72 | D50 = | 50.51 |
| RS = | 153.301 | DE = | 198.292 | DENSU= | 31.17 | TAU = | 0.39 |
| QST= | 69.891 | DEB = | 54.352 | DENSB= | 73.83 | | |
| W = | 1.000 | DV = | 247.890 | | | | |
| | | RF = | 22.165 | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PST= | 0.100 | | | | | | | | | |
| MLP= | 2.600 | | | | | | | | | |
| NC = | 3.000 | | | | | | | | | |

| MESH | X | ALIM | ALBR | DECBR | ALCYC | SURV | C | CC | B | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 707 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 12.88 |
| 28 | 500 | 99.71 | 99.86 | 99.99 | 99.91 | 100.00 | 97.28 | 96.50 | 0.56 | 7.70 |
| 35 | 354 | 99.32 | 99.65 | 99.96 | 99.76 | 99.99 | 97.28 | 96.50 | 0.43 | 4.61 |
| 48 | 250 | 98.40 | 99.07 | 99.78 | 99.35 | 99.95 | 97.27 | 96.50 | 0.33 | 2.76 |
| 65 | 177 | 96.05 | 97.16 | 98.89 | 98.00 | 99.83 | 97.23 | 96.44 | 0.25 | 1.65 |
| 100 | 125 | 89.31 | 89.72 | 94.31 | 92.74 | 99.37 | 96.48 | 95.47 | 0.19 | 0.99 |
| 150 | 88 | 77.69 | 70.09 | 79.26 | 78.77 | 97.80 | 91.50 | 89.08 | 0.15 | 0.59 |
| 200 | 63 | 65.36 | 40.62 | 52.67 | 56.65 | 91.79 | 76.82 | 70.22 | 0.11 | 0.35 |
| 270 | 44 | 53.99 | 19.65 | 30.56 | 37.90 | 77.91 | 52.10 | 38.45 | 0.08 | 0.21 |
| 400 | 31 | 42.73 | 11.05 | 19.18 | 24.55 | 60.56 | 37.62 | 19.86 | 0.06 | 0.13 |
| 500 | 22 | 33.96 | 7.28 | 13.17 | 19.48 | 44.87 | 30.14 | 10.24 | 0.04 | 0.08 |
| 1 | 16 | 25.36 | 4.88 | 9.11 | 14.20 | 34.64 | 26.29 | 5.30 | 0.03 | 0.05 |
| 2 | 11 | 18.94 | 3.40 | 6.42 | 10.34 | 25.56 | 23.66 | 1.92 | 0.02 | 0.03 |
| 3 | 8 | 14.14 | 2.45 | 4.60 | 7.59 | 18.85 | 22.30 | 0.17 | 0.01 | 0.02 |
| 4 | 5 | 10.56 | 1.80 | 3.33 | 5.59 | 13.90 | 22.17 | 0.00 | 0.00 | 0.00 |

Model # II

d) Circuit Feed Rate: 61.96 t/h

Rod Mill Data / Model # 2

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GAUDIN-SCHUHMANN

MODULUS= 1290.00 SLOPE= 2.00

| MESH | X | GPT | RETM | W | G |
|---|---|---|---|---|---|
| 7200 | 38100 | 100.00 | 100.00 | 1.00000 | 1.00000 |
| 5670 | 29420 | 92.70 | 100.00 | 0.95700 | 0.85411 |
| 4230 | 21230 | 89.50 | 100.00 | 0.89200 | 0.72854 |
| 3360 | 17230 | 81.80 | 100.00 | 0.82700 | 0.62394 |
| 2490 | 13230 | 80.20 | 100.00 | 0.75060 | 0.53364 |
| 1860 | 9603 | 80.80 | 100.00 | 0.69210 | 0.45726 |
| 1320 | 6699 | 82.90 | 100.00 | 0.63790 | 0.39134 |
| 930 | 4297 | 82.50 | 100.00 | 0.61290 | 0.33537 |
| 660 | 2763 | 82.60 | 99.50 | 0.57990 | 0.29538 |
| 470 | 1851 | 82.30 | 97.94 | 0.55460 | 0.26417 |
| 330 | 1195 | 78.80 | 94.34 | 0.54010 | 0.24067 |
| 230 | 743 | 80.20 | 90.58 | 0.50980 | 0.21934 |
| 160 | 451 | 78.80 | 87.52 | 0.49010 | 0.19589 |
| 115 | 317 | 75.50 | 84.38 | 0.47840 | 0.17762 |
| 80 | 225 | 75.20 | 82.14 | 0.47010 | 0.16357 |
| 60 | 170 | 74.40 | 80.02 | 0.46715 | 0.15594 |
| 40 | 142 | 73.30 | 78.17 | 0.46510 | 0.15044 |
| 30 | 105 | 72.10 | 76.87 | 0.46360 | 0.14641 |
| 20 | 78 | 71.00 | 75.94 | 0.46260 | 0.14358 |
| 14 | 53 | 70.80 | 74.99 | 0.46180 | 0.14152 |
| 10 | 37 | 70.60 | 74.24 | 0.46120 | 0.14018 |
| 0 | 25 | 68.20 | 73.58 | 0.00000 | 0.00000 |

RESULTATS

CIRCUIT PRIMAIRE.

VARIABLES D'ENTREE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| HCI1]= | 0.000 | HCI5]= | 0.330 | HCI9] = | 0.950 | HCI13]= | 1.478 |
| HCI2]= | 0.010 | HCI6]= | 0.047 | HCI10]= | 5.396 | HCI14]= | 2.889 |
| HCI3]= | 0.001 | HCI7]= | 0.000 | HCI11]= | 2.589 | HCI15]= | -0.024 |
| HCI4]= | 1.258 | HCI8]= | -10.710 | HCI12]= | 1.402 | HCI16]= | 0.030 |

| | |
|---|---|
| RO = | 4.50 |
| OF = | 17.39 |
| DE1= | 5.00 |
| DE2= | 17.50 |
| PST= | 0.100 |
| MLP= | 2.600 |
| NC = | 1.000 |

VARIABLES DE SORTIE

| | | | |
|---|---|---|---|
| CIR= 1.388 | DESU= 39.890 | DENS =74.31 | D150= 61.15 |
| DS =147.949 | RE = 11.265 | DENSO=88.42 | D50 =115.52 |
| RS = 85.996 | DE = 51.155 | DENSU=60.83 | TAU = 1.29 |
| QBT= 61.953 | DER= 28.765 | DENSR=74.94 | |
| W = 1.000 | DV = 84.032 | | |
| | RF = 22.021 | | |

| MESH | X | ALIM | ALBR | DECBR | ALCYC | SURV | C | CC | B | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 2830 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 1.00 | 31.41 |
| 8 | 2000 | 99.58 | 99.69 | 100.00 | 99.82 | 100.00 | 100.00 | 100.00 | 0.81 | 19.80 |
| 10 | 1410 | 97.96 | 98.53 | 100.00 | 99.15 | 100.00 | 100.00 | 100.00 | 0.65 | 12.48 |
| 14 | 1000 | 94.66 | 96.11 | 99.96 | 97.74 | 100.00 | 99.24 | 99.03 | 0.52 | 7.86 |
| 20 | 707 | 89.55 | 92.28 | 99.77 | 95.49 | 99.96 | 98.43 | 97.99 | 0.42 | 4.96 |
| 28 | 500 | 82.92 | 86.88 | 99.06 | 92.30 | 99.84 | 97.62 | 96.94 | 0.33 | 3.12 |
| 35 | 354 | 75.28 | 79.53 | 97.05 | 87.93 | 99.59 | 96.63 | 95.68 | 0.27 | 1.97 |
| 48 | 250 | 67.16 | 69.37 | 92.39 | 81.82 | 99.10 | 94.14 | 92.49 | 0.21 | 1.24 |
| 65 | 177 | 59.02 | 55.28 | 83.29 | 73.12 | 97.88 | 86.41 | 82.57 | 0.17 | 0.78 |
| 100 | 125 | 51.17 | 38.17 | 69.12 | 61.61 | 94.14 | 67.09 | 57.79 | 0.14 | 0.49 |
| 150 | 88 | 43.87 | 25.05 | 54.84 | 50.25 | 85.21 | 44.15 | 28.38 | 0.11 | 0.31 |
| 200 | 63 | 37.24 | 18.28 | 44.27 | 41.33 | 73.32 | 33.10 | 14.21 | 0.09 | 0.20 |
| 270 | 44 | 31.29 | 14.10 | 35.94 | 33.99 | 61.60 | 27.36 | 6.84 | 0.07 | 0.12 |
| 400 | 31 | 25.24 | 10.80 | 28.23 | 26.98 | 49.43 | 24.53 | 3.22 | 0.05 | 0.08 |
| 500 | 22 | 20.58 | 8.50 | 22.23 | 21.54 | 39.63 | 22.95 | 1.19 | 0.00 | 0.00 |



Model # II

CIRCUIT SECONDAIRE

VARIABLES D'ENTREE

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HCE13= | 0,000 | HCE53= | 0,240 | HCE93= | 0,965 | HCE133= | 1,000 | PH = | 1,00 |
| HCE27= | 0,003 | HCE67= | 0,074 | HCE107= | 5,320 | HCE147= | 2,758 | LF = | 32,39 |
| HCE33= | 0,000 | HCE73= | 0,060 | HCE113= | 2,758 | HCE153= | 0,000 | HF1= | 76,50 |
| HCE47= | 1,532 | HCE87= | 14,430 | HCE127= | 1,778 | HCE163= | 0,000 | HF2= | 3,95 |

VARIABLES DE SORTIE

| | | | |
|---|---|---|---|
| CTP= 1,487 | DESU=119,640 | DENS =51,14 | D150=106,86 |
| DS =154,045 | DE = 97,556 | DENSO=76,92 | D50 = 49,83 |
| RS = 92,115 | DS =147,196 | DENSU=54,13 | TAU = 0,65 |
| DST= 61,950 | DER = 30,806 | DENSP=73,94 | |
| M = 1,000 | DU =181,432 | | |
| | RE = 18,720 | | |

| MESH | X | ALTA | ALBR | BECHE | ALPYC | SUBU | C | TT | R | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 707 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 100,00 | 1,60 | 12,88 |
| 28 | 500 | 99,84 | 99,89 | 100,00 | 99,93 | 100,00 | 100,00 | 100,00 | 0,54 | 7,26 |
| 35 | 354 | 99,59 | 99,71 | 99,99 | 99,83 | 100,00 | 97,16 | 96,50 | 0,43 | 4,41 |
| 48 | 250 | 99,16 | 99,33 | 99,99 | 99,50 | 99,98 | 97,15 | 96,50 | 0,33 | 2,74 |
| 65 | 177 | 97,88 | 98,19 | 99,97 | 98,89 | 99,93 | 97,11 | 96,45 | 0,25 | 1,65 |
| 100 | 125 | 94,14 | 93,80 | 97,56 | 96,19 | 99,74 | 96,79 | 95,54 | 0,19 | 0,99 |
| 150 | 88 | 85,21 | 79,24 | 88,47 | 87,16 | 98,93 | 91,49 | 89,53 | 0,15 | 0,59 |
| 200 | 63 | 73,32 | 52,01 | 66,69 | 69,36 | 95,16 | 76,65 | 71,28 | 0,11 | 0,35 |
| 270 | 44 | 61,60 | 27,21 | 42,23 | 50,02 | 83,93 | 50,79 | 39,46 | 0,09 | 0,21 |
| 400 | 31 | 49,43 | 15,35 | 27,07 | 36,04 | 66,85 | 35,28 | 20,38 | 0,06 | 0,13 |
| 500 | 22 | 39,63 | 10,06 | 18,67 | 27,10 | 52,43 | 27,27 | 10,51 | 0,04 | 0,08 |
| 1 | 16 | 29,59 | 6,64 | 12,89 | 19,61 | 38,88 | 23,16 | 5,46 | 0,03 | 0,05 |
| 2 | 11 | 22,09 | 4,59 | 9,07 | 14,31 | 28,76 | 20,35 | 2,01 | 0,02 | 0,03 |
| 3 | 8 | 16,50 | 3,30 | 6,50 | 10,52 | 21,25 | 18,91 | 0,23 | 0,01 | 0,02 |
| 4 | 5 | 12,32 | 2,43 | 4,70 | 7,77 | 15,70 | 18,72 | 0,00 | 0,00 | 0,00 |



Model # II